Industrial QUALITY CONTROL

VOL. III MAY, 1947 NO. 6

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Quality Control Course
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An eight-day course in **Quality Control for the Mechanical Industries** will be offered by the Rochester Institute of Technology, September 9 through September 18, 1947. The course will be held in Endicott, New York, with classes meeting in the IBM Homestead. This course is a basic training program in Quality Control. Emphasis will be placed on the practical applications of quality control to problems which exist in the mechanical industries. Individuals from outside the Endicott area are welcome to enroll, as living accommodations will be available at the Hotel Frederick in Endicott.

In addition to the basic course a series of seminars will be held concurrently in advance quality control techniques. Twenty hours of instruction will be offered on such subjects as: Correlation, the "t" significance test, analysis of variance, design of experiments, and advanced work in sampling. Individuals with previous training or experience are welcome to enroll for these seminars.

Further inquiries concerning either of these two programs should be addressed to: Alfred L. Davis, Associate Director, Rochester Institute of Technology, Rochester 8, New York.

An Advanced Course
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Statistical Methods
Purdue University
June 27 to July 5

The course is designed for those who have had the equivalent of one of the intensive courses in statistical quality control given during and after the war, and who want to learn more about the statistical approach to industrial problems.

For additional information write to, Professor Irving W. Burr, Purdue University, Lafayette, Ind.

Industrial Quality Control

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George D. Edwards, President;
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Correspondence concerning membership and allied matters should be addressed to,

Ralph E. Wareham,
Executive Secretary,
305 E. 43rd St.
New York 17, N. Y.

Correspondence concerning institutional subscriptions, financial matters and requests for back issues should be addressed to,

Alfred L. Davis, Treasurer
Rochester Institute of Technology
Rochester 8, N. Y.

Editorial correspondence and requests for copyright releases should be addressed to,

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Volume I, which includes the July, 1944, September, 1944, November, 1944, January, 1945, March, 1945, and May, 1945, issues, is available at a price of $5.00. Volume II, which includes the July, 1945, September, 1945, November, 1945, January, 1946, March, 1946 and May, 1946 issues, is also available at a price of $5.00.

QUALITY CONTROL IN THE CHEMICAL INDUSTRY

II: Statistical Quality Control in the Chemical Laboratory

GRANT WERNIMONT

INDUSTRIAL LABORATORY, EASTMAN KODAK COMPANY, ROCHESTER, N. Y.

The role of chemical testing in chemical-process manufacturing is somewhat similar to that of the test gage in piece-parts manufacturing. The chemical-process production man takes samples from his production line just as piece-parts production men do. Instead of reaching for a measuring gage, however, the chemical-process man must send the sample to the laboratory for a chemical test.

Now the simplest chemical test is much more complicated than a gage measurement. The chemist, the test method and the testing apparatus all contribute to the variability of chemical test results, whereas precision test gages are designed so that the same results will be obtained, for a given measurement, no matter who uses the gage.

The analytical chemist should be interested in Statistical Quality Control because it will help him estimate the variability of his test methods. It will help him find the reasons why some of his methods are not reliable. It will also help him to maintain his test methods at a satisfactory level of precision and accuracy.

Statistical Quality Control is something more than tabulating test results, striking averages and estimating standard deviations. Statistical Quality Control puts "operational meaning" into the results of these statistical calculations. For example, we may say that the average of the results, in Table 1, for the determination of water in an organic liquid differs, from the

Table 1

Analysis of a 0.50 Per Cent Solution of Water in Methanol using the method of Karl Fischer

Anal. No.	Per Cent Water Found
1	0.52
2	0.64
3	0.57
4	0.56
5	0.53
6	0.55
7	0.50
8	0.54
9	0.55
10	0.56

Average $(\overline{X})$ 0.552%

Std. Dev. $S = \sqrt{\sum (X_i - \overline{X})^2/(n-1)} = 0.037\%$

Std. Error of Av. $= (S/\sqrt{n}) = 0.0118\%$

Student's $t = \dfrac{(\overline{X}-0.50)}{S/\sqrt{n}} = 4.41$

amount of water known to be present, by 0.052 per cent; we may calculate the standard error of this average to be 0.0118 per cent; and we may conclude that the value of 4.41 for "Student's" t is significantly greater than we might expect it to be by chance alone. But this does not answer the question we really want to know about the quality (precision and accuracy) of the test method: Is the Karl Fischer method reliable, and therefore useful, in the hands of various analysts in widely separated laboratories? We must put operational meaning into our statistics to answer questions like this. In this case, we must have more information about how the data were collected than has been disclosed in the table: Are these the results of a single analyst or of several analysts? Were they obtained on the same day or on different days? Are they single determinations or averages of two or more determinations?

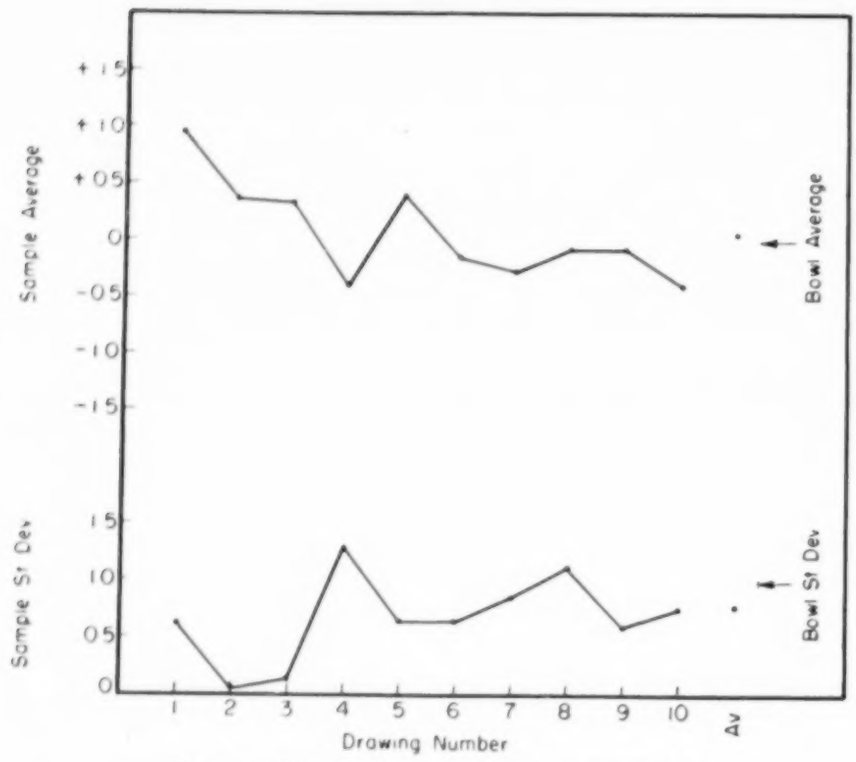
The problem of taking small samples from a large lot becomes very evident when we begin to use statistical methods in the chemical laboratory. Chemists are familiar with the idea of taking samples from a lot of material for chemical analysis. They may not be so familiar with the logic involved when we make judgments about the quality of the unknown (and perhaps unknowable) lot, using the information we get from the tests on samples taken from the lot.

The relation of a sample to the lot from which it was taken is conveniently illustrated by means of drawing marked chips from a bowl. Shewhart[1] has recorded the results of such a drawing experiment in which 997 chips were marked with numbers to conform to a normal distribution curve. The chips were drawn from the bowl in groups of four with replacement and Figure 1 shows the averages and standard deviations for the first ten drawings.

The same bowl furnished all of these samples, yet we get ten different values for the average of a

1. "The Economic Control of Manufactured Product," W. A. Shewhart, D. Van Nostrand Company, Inc., New York 1931, p. 442.

FIGURE 1



Drawings From Shewhart's Bowl of Chips in Groups of Four

sample of four chips drawn at the same time from the bowl. We surely cannot infer that the average of any small sample is necessarily the average of the bowl although it turns out that the grand average of a large number of small sample averages is always close to the average of the bowl.

In a similar way we see that the sample standard deviations fluctuate even though the standard deviation of the bowl is fixed; but the average of the small sample standard deviations is always smaller than the standard deviation of the bowl.

The analyst must face this "small sample" problem almost every time he tries to apply statistical methods in the laboratory. Any set of test results can be visualized as a small sample from a large lot. In many cases the lot, or the population as the statistician calls it, is infinite. The results in Table 1 are a small sample from a lot of test results which includes all tests that could be run on that batch of known solution before it was used up. Many more solutions could be made up and we may imagine a lot of these test results which is infinitely large. An analyst should never lose sight of the fact that what he claims to know about the "bowl" must be inferred from what he has found out by observing small samples from the "bowl."

A second problem arises when we apply statistical methods in the laboratory. The "bowl" of test results may contain two or more lots and not just one. The lot averages may be different and the distribution of individual results within the lots may not be the same. In the case of the Karl Fischer method, there may be a different lot of results for each analyst who uses the method. It is even possible that the same analyst obtains results on different days which are samples from different lots of test results, even though the known solution was absolutely uniform. This is why it is so important to know more about how the data for Karl Fischer moisture determinations (Table I) were collected.

Statisticians have devised many techniques to help make inferences about the lot on the basis of what is known about samples taken from the lot. Some of these techniques are quite involved and require a good knowledge of higher mathematics in order to be understood and used. The control chart is a simple yet versatile statistical technique which analysts can easily learn to understand and use. It can be used to help make reliable inferences about what is in the analyst's "bowl" of test results.[2] It makes use of a series of small groups (samples) of results taken from the "bowl."

2. Use of Control Charts in the Analytical Laboratory, Grant Wernimont, Ind. Eng. Chem., Anal. Ed. *18*, 587 (1946).

Table II

Determination of a Parr Calorimeter Constant

Day	Av. of Four Determinations BTU/lb/°F	Range of Four Determinations BTU/lb/°F
1	2435.6	13.5
2	2433.6	11.3
3	2428.8	10.0
4	2428.6	5.6
5	2435.9	18.7
6	2441.7	13.6
7	2433.7	9.9
8	2437.8	14.8
Average	2434.5	12.2

Control Limits for Future Calibrations BTU/lb/°F

$\sigma' = \bar{R}/d_2 = 12.2/2.059 = 5.92$ BTU/lb/°F

	Ranges				Averages			
n	2	3	4	5	2	3	4	5
U.C.L.	21.8	25.8	27.8	29.1	2447.1	2444.8	2443.4	2442.5
Av.	6.7	10.0	12.2	13.8	2434.5	2434.5	2434.5	2434.5
L.C.L.	0	0	0	0	2421.9	2424.2	2425.6	2426.5

A control chart may be described as a graphic presentation of test results in a manner so that the variability of all the results is compared, statistically, with the average variability within arbitrary small groups (samples) of the results. The chart is said to show evidence of "control" when there is no more variation among all the results than corresponds to the average variation within the groups. In this case we can infer that the "bowl" contains a single lot of test results and we can make reliable estimates of the average value of the lot and the distribution of individual results within the lot.

The results of a series of Parr calorimeter calibrations are shown in Table II. Four determinations of the constant were made on eight different days over a period of several months by four different analysts. The procedure was to burn a weighed amount of benzoic acid (heat value known) in the calorimeter and observe the temperature rise in the water surrounding the bomb. We want to establish the most reliable value for the calorimeter constant because this value will be used to make routine determinations of the heating value of fuel. We also want to maintain a check on the value of the constant so that it can be redetermined when (and only when) it has changed.

A control chart for these data is shown in Figure 2. The lower graph for daily ranges shows that they are all within their control limits; we may infer that the imaginary "bowl" of ranges of four calibrations made on the same day contains a single lot. Daily standard deviations might have been used in place of ranges but it can be shown that essentially the same inferences can be made using ranges so long as the small groups contain no more than ten individuals; the arithmetic is much simpler when ranges are used. The standard deviation, σ', of single calibrations made on the same day is 5.9 BTU/lb/°F.

The upper graph shows that the daily averages are also all within the control limits based on average daily ranges; from this we may infer that the "bowl" of calibrations made on different days contains a single lot of results for averages. In other words there is no more variation in the day-to-day calibration of the calorimeter than corresponds to the within-a-day standard deviation of 5.9 BTU/lb/°F. We may accept 2434.5 BTU/lb/°F as the best estimate of the calorimeter constant and we can expect the average of any group of 32 calibrations to be within the limits,

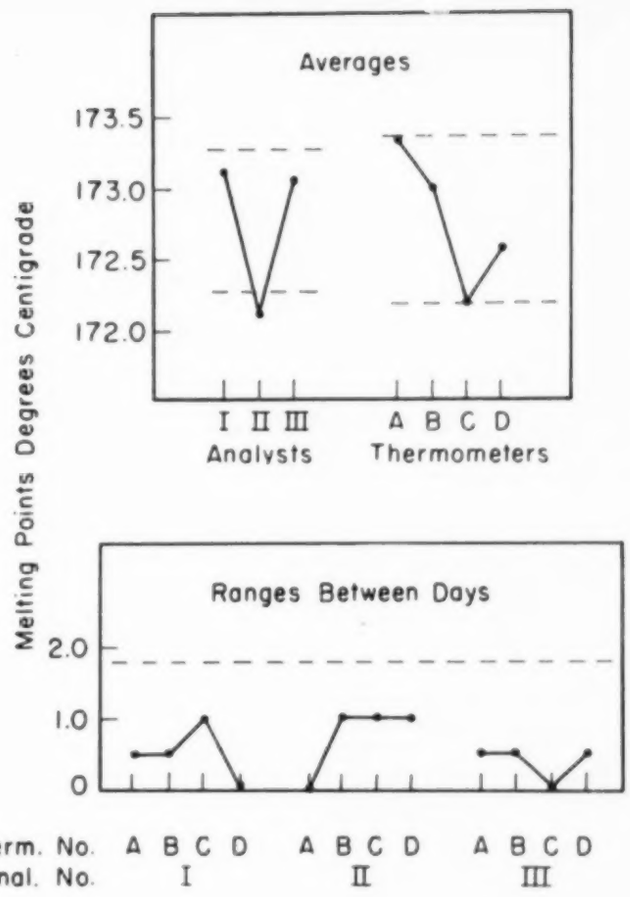
$$2434.5 \pm 3/\sqrt{32}(5.9) = 2434.5 \pm 3.1 \text{ BTU/lb/°F.}$$

We can maintain a check on this calibration at regular intervals and so long as the averages and ranges of calibrations made on the same day remain within the control limits shown in Table II we may infer that the calibration value of 2434.5 BTU/lb/°F still holds good.

When a control chart shows evidence of lack of control, we must infer that the "bowl" contains more than one lot of test results. We are then faced with the problem of locating and controlling the cause of the trouble. Sometimes this can be done by continuing the testing program and doing a little detective work just as soon as results are obtained which are outside their control limits. Another course of action is deliberately to change various steps in the procedure being studied, and watch the course of the results on the chart. It is quite easy to correlate these changes with the control chart and thus answer, with a high degree of certainty, the question of whether the changes had any effect on the results.

A more objective approach is to design a series of experiments so that the effects of different factors, which might be responsible for the appearance of different lots in our "bowl," can be separated and compared. This is called factorial analysis, and control chart methods can be used for simple factorial

FIGURE 2



CONTROL CHARTS FOR MELTING POINT DETERMINATIONS

Table III

Comparison of Thermometer and Analyst Variability Determination of Melting Point of Hydroquinone °C.

Analysts	Day	Thermometer A	B	C	D	Analyst Average
I	1	174.0	173.0	171.5	173.5	
	2	173.5	173.5	172.5	173.5	173.12
II	1	173.0	172.0	171.0	171.0	
	2	173.0	173.0	172.0	172.0	172.12
III	1	173.5	173.0	173.0	172.5	
	2	173.0	173.5	173.0	173.0	173.06
Thermometer Average		173.33	173.00	172.17	172.58	

Average Range between days 0.54

$\sigma' = \bar{R}/d_2$ 0.48

Control Limits

$\sigma' = 0.48$ °C

	Range of Two	Average of 2	Analyst Average of 8	Thermometer Average of 6
U.C.L.	1.8	173.19	173.28	173.36
Av.	0.54	172.77	172.77	172.77
L.C.L.	0	172.35	172.26	172.18

experiments if enough data can be secured to permit working with two or more measurements made under the same conditions.

The results of such an experiment, to find out why the variability of routine melting point determinations was so great, are shown in Table III. Four new uncalibrated thermometers of the specified quality were used by three analysts to determine the melting point of a controlled sample of hydroquinone following a specified procedure. The analysts all used the same heating bath. One of them had never used the procedure while the other two were making such measurements every day. The new analyst was given no verbal instructions but was asked to follow the specified procedure as closely as he could. Each analyst made a single melting point determination using each thermometer on each of two different days.

The experiment was designed to test the following possible causes of excessive variability:

(1) Variability among thermometers.

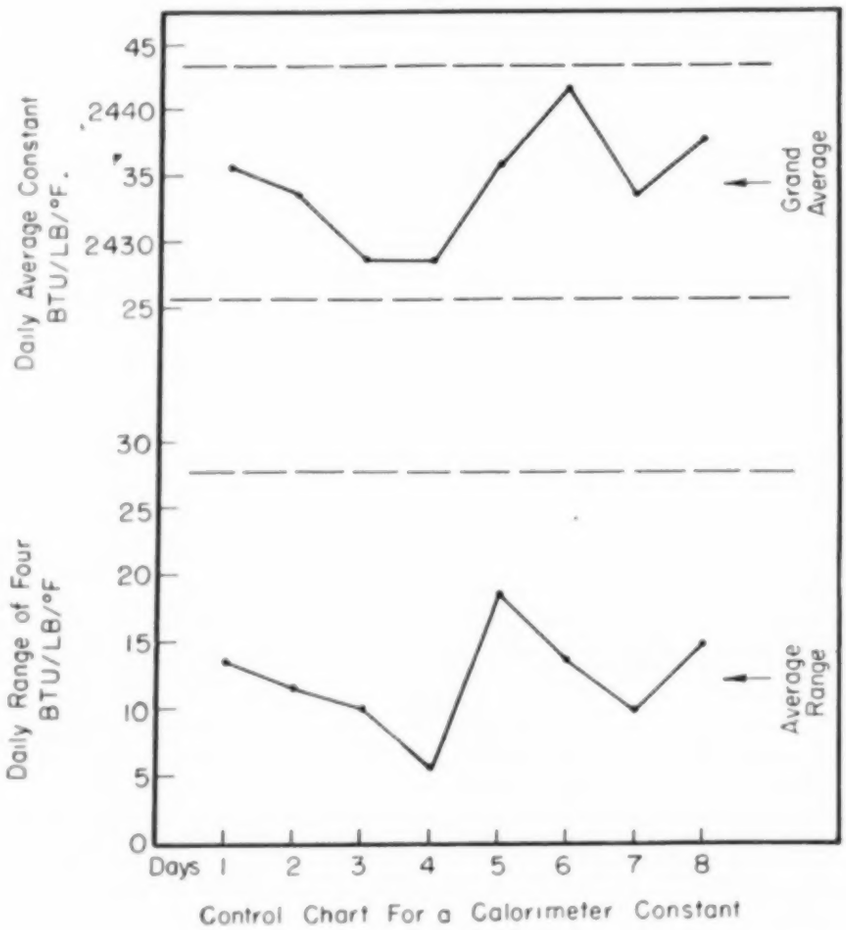
(2) Variability among analysts both experienced and inexperienced.

(3) Inherent day-to-day variability of the test.

The thermometer variability is reflected in the behavior of the averages of the columns in Table III because each operator has contributed variability equally to the thermometer averages while each thermometer contributes only to its own average. Similarly, the analysts' averages can be used to estimate their variability because each thermometer was used the same number of times by the three analysts. The average day-to-day variation with the same operator-thermometer combination estimates the inherent test variability.

The control chart in Figure 3 shows the results of the experiment. The lower graph for range of values for day-to-day variation shows all within their control limits and we infer that the "bowl" for ranges of determinations made using the same thermometer on different days contains a single lot. We can now use this average

FIGURE 3



Control Chart For a Calorimeter Constant

Table IV
Copper Content of Bronze Castings

Casting No.	Sample	Per Cent Copper X_1	X_2	$\bar{X}$	R
1	A	85.54	85.56	85.55	0.02
	B	85.51	85.54	85.52	0.03
2	A	85.54	85.60	85.57	0.06
	B	85.25	85.25	85.25	0.00
3	A	85.72	85.77	85.74	0.05
	B	84.94	84.95	84.94	0.01
4	A	85.48	85.50	85.49	0.02
	B	84.98	85.02	85.00	0.04
5	A	85.54	85.57	85.56	0.03
	B	85.84	85.84	85.84	0.00
6	A	85.72	85.86	85.79	0.14
	B	85.81	85.91	85.86	0.10
7	A	85.72	85.76	85.74	0.04
	B	85.81	85.84	85.82	0.03
8	A	86.12	86.12	86.12	0.00
	B	86.12	86.20	86.16	0.08
9	A	85.47	85.49	85.48	0.02
	B	85.75	85.77	85.76	0.02
10	A	84.98	85.10	85.04	0.12
	B	85.90	85.90	85.90	0.00
11	A	85.12	85.17	85.14	0.05
	B	85.18	85.24	85.21	0.06
			Average	85.57	0.0418

Control Limits for Groups of Two

$\sigma' = \bar{R}\, d_2 = 0.0418 \quad 1.128 = 0.037$ per cent Copper

	Ranges	Averages
U.C.L.	0.14	85.65
Av.	0.0418	85.57
L.C.L.	0	85.49

range to set control limits for the two sets of averages. The thermometers and the operators both show more variation than corresponds to the inherent day-to-day variability of the test. We infer that the "bowl" contains more than one lot for analysts and for thermometers.

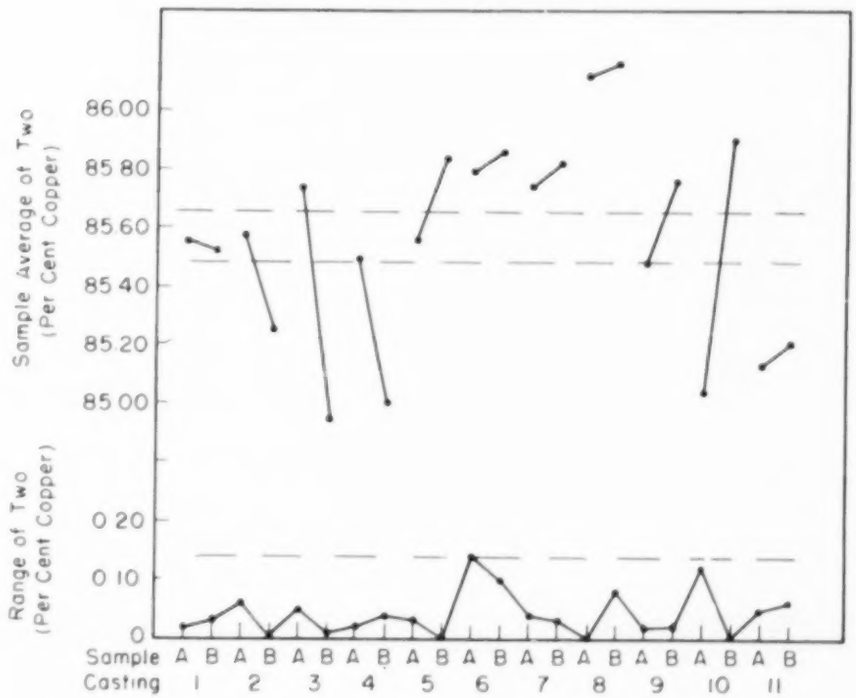
It was found that the inexperienced analyst interpreted parts of the specified procedure somewhat differently than the experienced analysts. Thus, it was necessary to clarify the procedure. The excessive thermometer variation can be removed by using higher grade thermometers.

In some cases it is not possible to find the factors which cause more than one lot of test results to be present in the "bowl"; and it may not be desirable or even possible to remove the causes after they are found. The control chart in Figure 4 shows the results (See Table IV) of electrolytic copper determinations made on a series of bronze castings all poured from a single melt of the alloy. Two samples were taken from each casting and duplicate electrolytic copper determinations were made on each sample. The lower graph for ranges of duplicate determination on the same sample shows evidence of fairly good control. We may infer that the "bowl" contains one lot of results in so far as the variability of duplicate determinations on the same sample is concerned.

The upper graph for sample averages, however, shows evidence of lack of control; there is more variation among the sample averages than corresponds to the average range of duplicate determinations made on the same sample. We must infer that this "bowl" contains more than one lot of test results. The lots have about the same standard deviation ($\sigma' = \bar{R}/d_2 = .037$ per cent copper) but their averages fluctuate from sample to sample and casting to casting more than can be expected by chance errors of testing alone.

One course of action might be to find and remove the factors which are responsible for this ex-

FIGURE 4


Sample Average of Two (Per Cent Copper)
86.00
85.80
85.60
85.40
85.20
85.00
Range of Two (Per Cent Copper)
0.20
0.10
0
Sample A B A B A B A B A B A B A B A B A B A B A B
Casting 1 2 3 4 5 6 7 8 9 10 11

CONTROL CHART ELECTROLYTIC DETERMINATION OF COPPER IN SAMPLES OF BRONZE CASTINGS

(Limits Based on Range of Duplicate Determinations)

Table V
Copper Content of Bronze Castings

Casting No.	Per Cent Copper Sample* A	B	$\bar{X}$	R
1	85.54	85.51	85.52	0.03
2	85.54	85.25	85.40	0.29
3	85.72	84.94	85.33	0.78
4	85.48	84.98	85.23	0.50
5	85.54	85.84	85.69	0.30
6	85.72	85.81	85.76	0.09
7	85.72	85.81	85.76	0.09
8	86.12	86.12	86.12	0.00
9	85.47	85.75	85.61	0.28
10	84.98	85.90	85.44	0.92
11	85.12	85.18	85.15	0.06
		Average	85.55	0.304

Control Limits for Groups of Two
$\sigma' = \bar{R}/d_2 = 0.304/1.128 = 0.27$ per cent Copper

	Range	Average
U.C.L.	0.99	86.12
Av.	0.304	85.55
L.C.L.	0	84.98

*These values were taken from the column for X_1 values in Table IV. The X_2 values will give essentially the same results.

cessive variation. But in this case it would not be economical to try to make castings so uniform that there would be no more variation among castings than corresponds to the average range of duplicate electrolytic determinations made on the same sample.

A better course of action is to group the test results by samples from the same casting rather than by duplicate tests made on the same sample. The control chart in Figure 5 shows the results (Table V) of the first of the duplicate electrolytic determinations made on the two samples from each casting. The lower graph for ranges of duplicate samples shows no evidence of lack of control. The standard deviation ($\sigma' = \bar{R}/d_2 = 0.304/1.128 = 0.27$ per cent copper) for this lot includes the variation of duplicate determinations on the same sample and the variation of samples taken from the same casting. There is no evidence of lack of control and we infer that the "bowl" contains a single lot of ranges.

The upper graph for casting averages shows no evidence of lack of control. This is the same as saying that there is no more variation among the castings than corresponds, statistically, to the average variability between samples taken from the same casting. The variability of the test method is negligible compared to the inherent variability of samples taken from the same casting.

It is interesting to compare the inference based on control chart analysis with the inferences we would get by using the more complicated method of Variance Analysis.[3] Table VI shows the results of Analysis of Variance of the calorimeter calibration data. The ratio of mean squares for "among days" and "within days" is not significantly greater than 1.00 so we infer that the "bowl" contains a single lot or population. An estimate for the standard deviation of individual determinations is

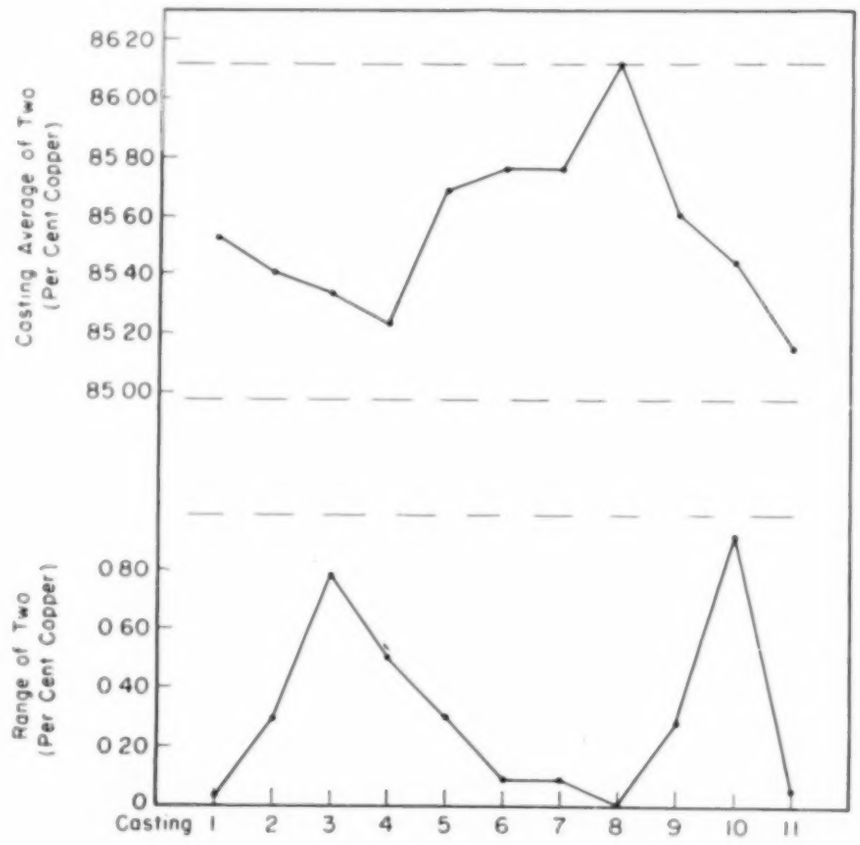
$$\sigma' = (1293.84/31)^{1/2}$$
$$= 6.5 \text{ BTU/lb/°F.}$$

The 0.99 fiducial limits for the grand average using Student's t, are,

$$2434.5 \pm 2.75 \times 6.5/(31)^{1/2} =$$
$$2434.5 \pm 3.2 \text{ BTU/lb/°F.}$$

3. See Control Charts Versus the Analysis of Variance, C. C. Craig, Industrial Quality Control, III, #4, p. 14 (1947).

FIGURE 5



CONTROL CHART FOR ELECTROLYTIC DETERMINATION OF COPPER IN BRONZE CASTINGS

(Limits Based on Range of Duplicate Samples)

The Analysis of Variance for the melting point experiment is shown in Table VII. Both the analysts and the thermometers show significant variation when compared to the residual mean square.

Here the method of variance analysis can tell us a little more about the test results than the control chart method does. The mean square for the interaction of thermometers and analysts is not significantly greater than the residual error. This means that the analysts show no preference for any of the thermometers and it gives us more confidence in the reliability of the test method.

Significant interactions are not uncommon in chemical laboratory test procedures and this should always be kept in mind when control charts are made for simple factorial experiments. The control chart method, as used here, will not show up interactions between the factors which are being studied.

The Analysis of Variance for the copper determinations is shown in Table VIII. The variation of samples within a casting is significantly greater than the variation of the duplicate chemical analysis. The castings do not show more variation than corresponds to the variation of samples within castings.

In all three cases we are led to essentially the same conclusions when either control chart methods or analysis of variance methods are used to analyze the data. Analysts should be encouraged to learn how to use variance anlysis and some of the other more complicated statistical procedures; but they should not overlook the wide use that can be made of the simple and easily understood control charts in the analytical laboratory.

Table VI
Analysis of Variance
Determination of a Calorimeter Constant

Source of Variation	D. of F.	Sum of Squares	Mean Square
Among days	7	536.21	76.60
Within days	24	757.63	31.57
Total	31	1293.84	

Table VII
Analysis of Variance
Melting Point of Hydroquinone

Source of Variation	D. of F.	Sum of Squares	Mean Square
Analysts (A)	2	5.0208	2.5104**
Thermometers (T)	3	4.6146	1.5382**
(A) x (T)	6	2.7182	.4530
Duplicates	12	2.6350	.2196
Total	23	14.9886	

**F—ratio significant at .01 level

Table VIII
Analysis of Variance
Determination of Copper in Bronze Castings

Source of Variation	D. of F.	Sum of Squares	Mean Square
Among Castings	10	3.2031	0.3203**
Within Samples	11	1.9003	0.1728**
Within tests	22	0.0423	0.0019
Total	43	5.1457	

**F—ratio significant at .01 level

III: Statistical Techniques for Production Control and Plant Scale Experimentation

CHARLES A. BICKING

HERCULES POWDER COMPANY

The Control Chart as a Basic Tool

In the introductory article of this series[1], it was pointed out that the control chart is a basic tool for process operators. Its maintenance is so simple that almost any grade of operator can handle it. It is so concise and to the point that any foreman or supervisor may interpret it and follow through with action to improve his process. No attempt was made to explain the method of constructing a control chart, but some of the adaptations commonly made in applying the charts to chemical processes were pointed out. The details of setting up the charts are covered adequately in the many texts and articles on the subject.

In a second article[2], elsewhere in this issue, specific uses of the control chart in chemical laboratories are described. Subsequent articles in the series, dealing with applications to specific industries, will follow the same pattern of concentrat-

1. "How Statistics Contributes to Quality Control in Chemical Industry," Industrial Quality Control, January, 1947.

2. "Statistical Quality Control in the Chemical Laboratory." Grant Wernimont, pages 5-11.

ing on discussion of the use rather than the mathematics of the control chart. The final effect of considering the use of the charts in varied circumstances should be to give them proper emphasis as quality control's most versatile tool.

The present article will deal principally with other tools than the control chart. Emphasis will be placed on the choice of statistical methods to suit a given problem and on the integration of the quality control program. Subsequent articles in the series will give additional applications of most of the methods mentioned and will describe in finer detail how they are used.

Statistical Methods and Scientific Thinking

The use of control charts always involves the exercise of choice in determining what factor to chart. This poses a problem at the very beginning which is of a technical rather than a statistical nature. A fundamental requirement of the individual seeking to apply quality control methods is that he be thoroughly grounded in the technical details of the process. Starting with a background of experience and familiarity with the process, he must preface application of any statistical method with the clearest of scientific thinking. Perhaps what those interested in the improvement of quality should insist on, even more than on sound methods, is clear thinking. Throughout industry there is needed thorough, objective thinking about process conditions, even before the application of statistical methods. Putting adequate tools in the hands of a man capable of thinking through the technical aspects of a problem multiplies his effectiveness. Not even the best of tools will be of much use if they are not coupled with a sound appreciation of the technical aspects of a problem. Thinking must accompany the use of statistical tools at every step. Beginning with the planning of a process study, through the interpretation of the results, to action to improve the process, each statistical fact must be weighed in the light of the surrounding economic and technical circumstances.

It has been suggested that in the best interest of industry, engineers should be trained in statistical methods rather than statisticians in production technology. The reasons for this view are apparent if there is proper appreciation of the dependence of choice of statistical method and of the interpretation of results on a sound technical knowledge of the process being studied.

The Functions of Industrial Statistics

It is important to keep in mind what the functions of industrial statistics really are. If that is done, there will not be a tendency to expect more from statistical studies than one should have been led to expect. For example, quality control methods are not self-correcting but are a means of indicating or predicting the need for corrective action. Furthermore, as commonly used, the methods do not detect an absolute or systematic error. Thus, the determination of the accuracy of a result is dependent upon the establishment of some standard which is more an engineering than a statistical problem.

Those things which may be expected of statistical methods may be outlined as follows:

1. Simple, effective means of obtaining, reporting, and analyzing data.
2. Means of determining whether future results may be predicted safely.
3. Measurement of the limits of variability of data.
4. Indication of the importance of relationships among variables.
5. Indication of cause and location of trouble.
6. Study of effect of changes or adjustments that have been made.

Practical Application of Statistical Laws

Each time an application of a statistical procedure is made, a certain pattern should be followed. This may be outlined as follows:

1. Select a suitable technique for the type of problem at hand. This involves selection of a suitable mathematical framework with which comparisons can be made. This framework usually involves dependence on the normal distribution curve.
2. Obtain data in sufficient quantity and of such quality that the results can be depended upon. Pay particular attention to the source and arrangement of data.
3. Select the probability limits (or "betting odds") so that estimates or predictions will be consistent with the technical and economic conditions existing.
4. Proceed to make the analysis with the cooperation of all personnel from management down.

It should be emphasized that the statistical methods suitable for practical use are all fundamentally simple. Little more than high school arithmetic or simple algebra at the most is required. Some of the methods are considerably involved, requiring close attention to the detail of the method, but none require difficult mathematics in their application. The unfortunate fact that technical training almost always includes higher mathematics but rarely includes even fundamental statistics is easily confirmed. Yet the opportunities for using statistics are frequent in the experience of most technical people. Capital should be made of the fact that much good can be had from an ability learned with comparative ease.

Limitations on Applications of the Control Chart

The problem of choice of the proper statistical method is accentuated in the chemical industry by the fact that the relationship of the variables is rarely simple and direct. Although in mechanical industries obvious uses for control charts may be apparent from the beginning of a study, it may be necessary in studying a chemical process to unravel the intricate interrelationship of variables before it can be determined which factor is suitable for charting.

A control chart for final product qualities may serve the purpose in mechanical industries of giving direct indication of the cause of variation. In chemical processes involving many variables it is not always easy to determine assignable causes of lack of control from such a chart. Too many of the effects overlap and obscure any

direct relationships that may exist. It is not always useful to an operator for taking action for this reason. In such a situation this sort of chart gives a valuable overall picture of average quality, of dispersion of results, of trends, or of significant changes in conditions.

Final product quality charts are thus most useful to supervisors and management in planning long-term action, in formulating operating instructions, or in setting specifications. The question arises as to how to determine which of the factors surrounding the process most decisively affect product quality. When this has been determined, it is obvious what factors should be charted by the process operators.

Determining the Relative Importance of Variables

It is necessary, therefore, to consider the process as a whole and determine the effect on the property which it is desired to control of all the known, measured or measurable factors in the process. One way suggested for doing this is to use the quality control technique known as "multiple correlation." By this means it is possible to determine the portion of product variability explained by all of the measured factors together and separately; the relative importance of the effect of these factors on the quality under study; the significance of the effect of each of the process factors; and the error of estimating the product quality from any known set of processing conditions. It enables the investigator to eliminate the least important variables from consideration first and concentrate on those which are proven to be significant. Thus corrective action may be directed to the most important source of variability. This source may then be studied profitably by control charts or other statistical means.

If an unsatisfactory proportion of variability has been explained by the multiple correlation procedure or if the error of observation is still large, it will be desirable to carry the study further. It may be profitable to measure the precision of the original quality measurements if it is not known. It may be desirable, on the other hand, to obtain measurements on additional process variables and add them to the correlation.

Technical knowledge of the process may bring to mind other factors which might affect the product measurement or might indicate that wider ranges of values than those used might have significant effects.

This might lead to further analysis of the variables considered or of new variables by the "analysis of variance" technique. It may be possible to obtain information for such an analysis by making experimental changes in process conditions or by making special runs in a pilot plant or laboratory scale experiment.

In any event, it would be desirable to keep the number of experimental runs to a minimum for reasons of time and economy. In order to do this, it would be necessary to use one of the principles of experimental design such as "factorial design." It is not feasible in a single paper to give instruction in how to carry out the various steps in an integrated study of the process such as the one just outlined. However, it is possible to describe, briefly, results of an actual study of this type, involving many of the commonly used quality control techniques. It is planned, therefore, to describe the results of an integrated study of the effect of three key processing conditions on the efficiency of a process.

Explaining the Efficiency of a Process

It was desired to improve the efficiency of a given process. Preliminary review of the technical aspects of the problem led to the belief that three measured factors in the process were most likely to affect efficiency. These factors were the total processing time, the purity of the raw material, and the amount of solvent used. It was believed that assignable causes of variation in efficiency would not be revealed by control charting the efficiency itself or any or all of the other measured variables, due to their inter-relation, the effect of unmeasured variables, and inability to measure efficiency or purity precisely. It was therefore proposed to run a multiple correlation to determine the effect of the three independent factors on the dependent factor, efficiency.

The multiple correlation technique is simply an extension of the well known technique of simple correlation between two variables. When the necessary sums of squares and sums of cross products are obtained a coefficient known as the Beta coefficient is calculated for each independent variable. The size of the Beta Coefficients depends on the order of importance of the effect of the independent variables on product efficiency. In this problem the Beta Coefficients indicated that Processing Time, Purity of Raw Material, and Amount of Solvent were important in decreasing order. It was therefore possible to solve three simultaneous equations involving all three process factors and two simultaneous equations for the two principal effects to get the rest of the information needed for the Table of Variance below.

The square root of the residual mean square (± 3.96) gives the standard deviation of efficiency values obtained from known values of the three process factors within the experimental range. An "F" test will indicate the significance of the effect of the three factors: processing time and purity are found to be highly significant, and amount of solvent insignificant.

It is known that the error in some of the test methods themselves may account for a considerable portion of the unexplained variation in efficiency. Therefore no further factors were added to this correlation. Technical means of improving the significant factors were considered. Emphasis was placed first on the processing time which was shown to be most important. This gives a clue as to where control charts may be kept

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Squares
Processing Time	2718.89	1	2718.89
Purity of Raw Material	700.11	1	700.11
Amount of Solvent	10.88	1	10.88
Residual	503.34	32	15.73
Total	3933.34	35	

profitably in the future. Although in this example, the effect of solvent rate is not significant, other information points to a high correlation between efficiency and solvent rate if a greater range of values is employed. It must be noted that this indicates the kind of thing that multiple correlation cannot do, namely, show the effect of varying any of the factors beyond the range of observed values. Further experimentation is the only answer to what will happen if the range of any of the factors considered is increased or if other factors normally closely controlled should be allowed to vary. For example, it is highly probable that shifts in temperature of processing will affect efficiency significantly. The close control normally exercised over temperature did not permit it to show up as important in the above study.

In order to minimize the number of test runs on the process equipment or in a pilot plant, the experiment to determine the effect of varying solvent rate and temperature should be set up with a factorial design. Suppose that it was desired to obtain more information on the effect of Purity (P), Solvent rate (S) and Temperature (T). Efficiency would be measured with each factor at two levels of appropriately large range according to the following table:

$P_1S_1T_1$
$P_1S_2T_1$
$P_1S_1T_2$
$P_1S_2T_2$
$P_2S_1T_1$
$P_2S_2T_1$
$P_2S_1T_2$
$P_2S_2T_2$

These data could then be analyzed by the analysis of variance technique to improve the knowledge of the significance of wide variations in the three factors of interest to the experimenter.

Filling the Gaps in Available Information

Only a brief outline of what can be done to extract the last bit of information from our measurements on the process and to insure maximum usefulness of experimentation has been indicated. It is expected that as the present series of articles on quality control in the chemical industries appears, further details will be given on how to carry out the various steps in the procedures mentioned. This is highly desirable since many statistical texts fail to make the transfer from theory to application in terms or in examples comprehensible to chemists or engineers.

The quality control profession has a long way to go in adapting to industry the techniques and manner of thinking of the statistician. Particular attention must be paid to the use of reliable methods and to the drawing of proper inferences from results. A good step is to precede control chart applications with thorough analysis of the relationship of variables, as has been suggested, so that when an operator is asked to keep a control chart his energies will be devoted to profitable ends.

Purposeful Application of Quality Control

In no other industry has it seemed more important than in the chemical industry to obtain a general orientation before tackling a control program. Nowhere is more conscientious thinking being done on the effective choice of techniques and on the making of proper inferences from the results of statistical analysis. It should be the source of some pride to the industry that this is so. It is possible that in this industry there has been a greater attempt to understand the basic principles of the methods in use and less willingness to accept certain approved forms as a matter of rote. This may explain the confidence expressed on all sides that the chemical industry is the most fertile field for the application of quality control methods.

When the problems of production have been thought through carefully and shrewd use has been made of statistical techniques, management learns to appreciate that a significant contribution is being made by those using quality control to the economical and profitable conduct of the business.

Statistical "Sleuthing" to Detect Bias in Visual Inspection

DAVID H. SCHWARTZ

QUARTERMASTER CORPS INSPECTION SERVICE*

Inspection for attributes is commonly regarded as a simple form of quality control. While this may be true from a statistical viewpoint, inspection for attributes often presents a host of technical difficulties never encountered in inspection for variables. Anyone who has worked with quality characteristics which are checked by visual comparison with pre-determined standards, knows how difficult it is to establish definite limits of acceptability for such characteristics and, once they have been established, to see that the inspector uses them properly. The latter problem is the subject of this article.

In visual inspection for workmanship, surface finish, formation, etc., the ability and character of the inspector are critical factors. This type of inspection is complicated by the frailty of both human judgment and human will power. The judg-

*This article does not necessarily represent the official viewpoint of the War Department.

ment of the inspector can, of course, be improved by training, but the objectiveness of the best trained inspector in interpreting the evidence of his eyes is subject to all sorts of biases.

Foremost among the biases affecting the "visual" inspector is the pressure exerted on him by production or purchasing personnel not to reject. Everyone knows how strong this pressure can be in acceptance sampling where the disposition of an entire lot or batch of product depends on how liberal the inspector happens to be in examining his sample. To the vendor, rejection means screening and reprocessing of a large quantity of product; to the buyer, it means a delinquency in meeting delivery schedules and resistance by the vendor (in a seller's market at any rate) to the placement of future contracts.

It seems reasonable to believe that the same pressures must exist in sampling for process control. Since a point beyond the limit on a control chart calls for investigation and possible stoppage of the process of manufacture, it must provoke strong objections from production personnel. Confronted by these objections, the inspector may forgive rejects to keep peace in the industrial family.

Inspection bias may also be due to faulty sampling, which is of course true in any kind of inspection, visual or otherwise. If the method of selecting sample units consistently tends to include a greater or a smaller percentage of defectives in the sample than in the lot, inspection results will be invalid.

When double or sequential sampling is being used, there is the additional bias arising from the inspector's desire to reduce his workload by terminating inspection on the initial sample of each lot or as soon thereafter as possible. This may lead him to find more defectives in the initial sample than it really contains and so make a quick rejection, or to find fewer defectives in the initial sample than it really contains, and so make a quick acceptance. In view of the constant pressure on the inspector not to reject, the latter is the more likely of the two.

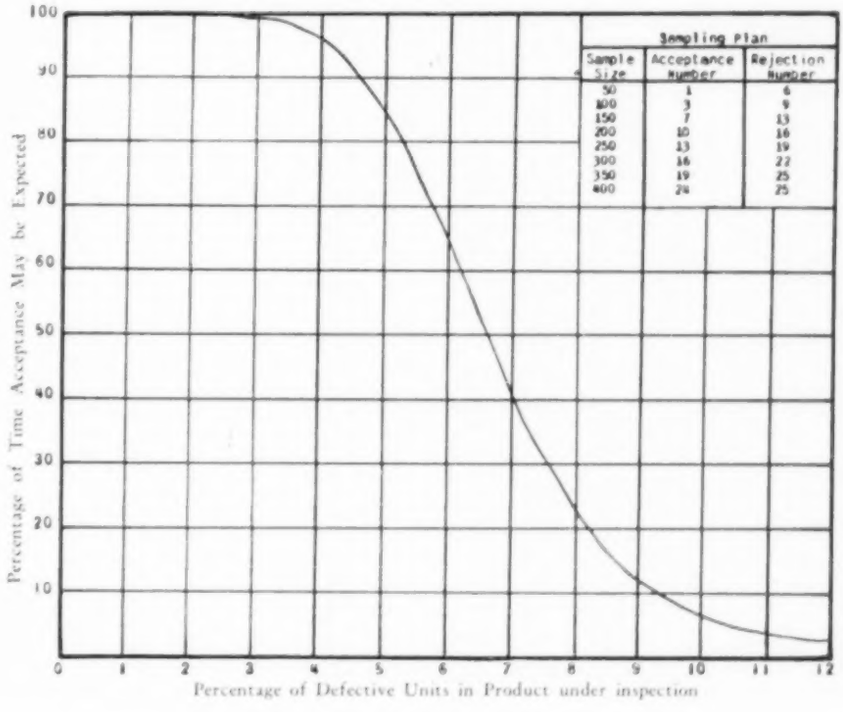
Biases may be conscious or unconscious on the part of the inspector, but recognition of their existence and constant surveillance to detect and weed them out is essential to any program of visual inspection. For purposes of detection, biases may be considered under two headings — consistent and inconsistent. Consistent biases exist when the inspector constantly uses more exacting or more liberal acceptance standards than he should. Inconsistent biases exist when the inspector changes his acceptance standards during the course of examination of each lot. Consistent biases can only be detected through independent check inspection by a second individual, and comparison of the check inspector's findings with those of the regular inspector. Inconsistent biases, on the other hand, can be detected through the use of statistical techniques.

The first method of statistical "sleuthing" is comparison of the actual frequency of rejection of lots (or frequency of points outside control limits) with the frequency to be expected on the basis of current quality performance. Quality performance is determined by periodic computation of the process average. The expected frequency of rejection (or of points out of control) is arrived at by consulting the operating characteristic curve of the particular sampling plan being used on the product.

An operating characteristic (or OC) curve reveals how frequently product of any given quality may be expected to pass the sampling plan under which it is being inspected. Every sampling plan (and every control chart) has its own operating characteristic curve, which can be worked out by more or less straight-forward statistical methods. The OC curve for a particular sampling plan is shown in Figure 1. This curve reveals, for example, that the sampling plan will, on the average, accept 40 out of every hundred lots, if the lots are 7% defective. Thus, if 30 lots are inspected and their process average is 7% defective, approximately 40% or about 12 lots, will be accepted and the remaining 18 rejected, **provided that inspection has been impartial.** If the inspector using this plan actually rejects only 2 or 3 out of 30 such lots, inconsistent bias is probably the cause.

FIGURE 1

EXAMPLE OF AN OPERATING CHARACTERISTIC (OC) CURVE



When considerable divergence is found between the actual and expected frequency of rejection, it is generally found also that the inspector has consistently recorded **almost** enough defectives to reject, but has rarely rejected, as illustrated in Table I.

TABLE 1

Sampling Plan			No. of Defectives Reported by Inspector for Sample of Each Lot									
Sample Size	Acceptance Number	Rejection Number	Lot No. 1	2	3	4	5	6	7	8	9	10
150	6	7	6	5	6	6	6	6	5	6	6	6

In double or sequential sampling, this condition may manifest itself as a tendency by the inspector to tally almost enough defectives in the initial sample to reject, but then find so few defectives in the second or third sample that he ultimately accepts the lot. Such a tendency can be detected by comparing the process average based on the inspector's initial samples with averages based on his second or third samples. Any substantial difference between the process average of first samples and that of subsequent samples indicates that the inspector is liberalizing his standards after the first sample. A similar check can be made in single sampling by requiring the inspector to keep separate records on the first and second half of each sample.

A second statistical technique which may be utilized to detect inconsistent bias is to check the number of lots consecutively accepted by the inspector against the number of consecutive acceptances which may reasonably be attributed to chance fluctuation alone. To illustrate: If the process average is 7% defective and the OC curve of the sampling plan being used gives product of that quality a 40 out of a hundred chance of acceptance, we would expect, on the average, to see 2 lots accepted for every 3 rejected. We would furthermore expect to see 5 lots accepted in a row only once in a hundred times. Thus, if an inspector accepted 5 lots in a row, we would be fairly safe in assuming the presence of bias.

This method, like the first, involves the use of the OC curve and a word of caution about operating characteristics is therefore germane. An OC curve predicts the expected frequency of rejection on the assumption that the process of manufacture is in a state of control at the computed level of quality. If the process is seriously out of control, straight-forward comparison of the actual and expected rates of rejection is impossible. Also, it is well to keep in mind that the OC curve's prediction is applicable to an infinite series of lots and, in any limited series, a margin must be allowed for sampling error.[1] The inspector should not be indicted when the percentage of lots he actually rejects is a bit different from the percentage the OC curve leads us to expect.

A third method of detecting bias is comparison of the average number of sample units per lot examined by the inspector with the expected number of sample units per lot. This method cannot, of course, be used with single sampling where the number of units inspected per lot is constant, but is extremely valuable in double or sequential sampling. When double or sequential sampling is used, the number of sample units required to reach a decision varies from lot to lot, but maintains an average which depends on the quality of product sampled. If quality is **good**, lots are quickly **accepted** and the average amount of sampling is low; if quality is **bad**, lots are quickly **rejected** and the average amount of sampling is likewise low. When quality is in the "twilight" zone — neither very good nor very bad — more work is required on each lot, and the average amount of sampling is then higher.

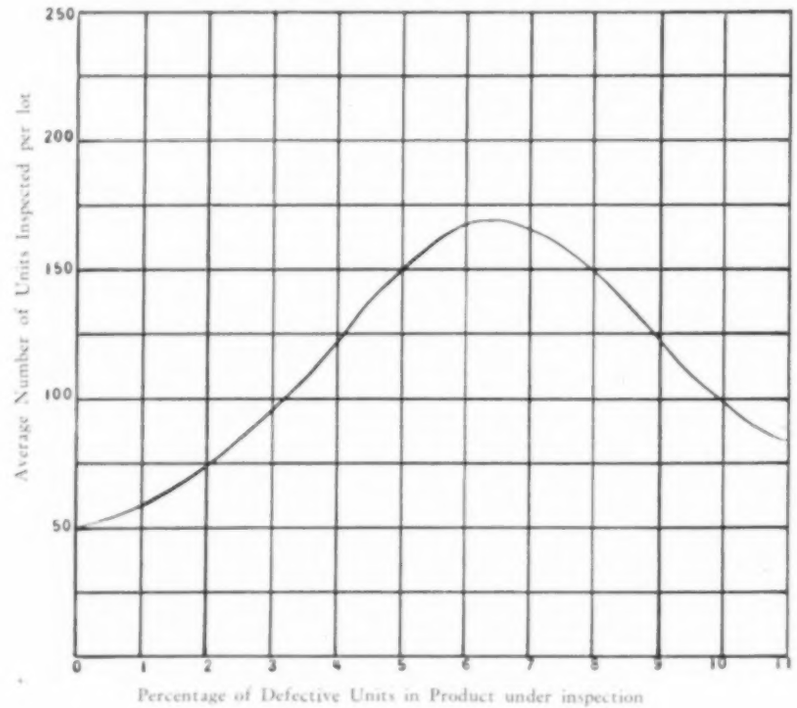
The exact amount of sampling which may be expected on product of any given quality is given by the average sample number (ASN) curve representing the particular double or sequential plan in use. A typical ASN curve is shown in Figure 2. This curve shows, for ex-

1. It is possible, by statistical methods, to determine just how much difference should be allowed between the actual and expected frequency of rejection before concluding that the inspector is guilty of bias. The author has found this added refinement more trouble than it is worth because other factors, such as the process being out of control, render the expected frequency of rejection something less than a statistically precise estimate.

FIGURE 2

EXAMPLE OF AN AVERAGE SAMPLE NUMBER (ASN) CURVE

(For same sampling plan as in Figure 1)



ample, that if a vendor's process average is 7% defective, the sampling plan will, on the average, require the inspector to examine about 170 units per lot. If the inspector has actually been examining substantially fewer or substantially more than 170 units per lot, it is evidence of bias.

This method is valuable because the other two methods (which utilize the frequency of rejection) can reveal bias only when a considerable number of rejections is expected, that is, when quality is poor. When quality is good, average sample size is the most sensitive of the three indicators of bias.

It may be argued that when quality is good bias need be of no concern, but this is valid only if quality can be relied on to remain good. Furthermore, if an inspector is someday assigned to a poor quality product, he will carry with him any tendency to yield under pressure, and it is easier to eliminate biases before they have become ingrained in the inspector's mind than after.

When there is evidence of inconsistent bias, one of three interpretations may generally be made:—

1. The inspector may be starting on each lot using the proper acceptance standards, but may be "loosening up" when he approaches a rejection number, i.e., the product is really bad and deserves to be rejected.

2. The inspector may be starting on each lot with the idea that he is not doing his job unless he finds a certain number of defectives, and therefore, "flyspecks" his first sample units. Later he tries to compensate for his early severity either by using the proper acceptance standards or by actually overlooking defective sample units. When this happens, the product may really be acceptable or may really be rejectable; there is no way of telling from the inspector's results.

3. The inspector may be including obviously defective units in his sample so that his sample is not random. This occurs frequently in the inspection of items like shoes, many defects of which are so obvious that they strike the inspector's eye before he has decided which units to include in his sample. Involuntarily, he reaches for the obvious defectives first and the proportion of defectives in the first part of his sample from each lot is consequently greater than that in the later parts of his sample. The solution to this problem is "predetermined" sampling, a procedure under which the inspector, before approaching each lot, chooses at random the serial numbers of locations of the units he will include in his sample. Then, if he notices any obviously defective units other than those in his predetermined sample, he removes them from the lot but does not include them with his sample results.

Elimination of inspection biases once they have been detected is an art in itself, discussion of which is beyond the scope of this article. Biases due to faulty procedures for selecting samples can be cured more or less mechanically. Biases arising in the inspector's mind are more difficult to root out. If bias is due to lack of knowledge, the inspector must be re-instructed, but re-instruction must always be supplemented by counter-pressure to offset the pressure of production personnel for acceptance regardless of quality.

SUMMARY

1. There are three chief causes of bias in visual inspection: pressure on the inspector to accept regardless of quality, non-random sampling technique, and desire of the inspector to reduce his workload under double or sequential sampling.

2. Bias is of two types, consistent and inconsistent. The latter can be detected by statistical analysis of inspection reports.

3. Techniques for detecting inconsistent bias are: Comparison of actual and expected frequency of rejection, checking the consecutive number of acceptances, and comparison of the actual and expected average sample size.

4. Statistical sleuthing to detect bias in visual inspection is a useful tool of management control.

New Uses for the Average Range

G. M. COHAN

GENERAL ELECTRIC X-RAY CORPORATION

It is a well-known fact that no matter how well centered a process is, if the variability exhibited in sampling is excessive, the process will yield scrap or rework or both. To determine excessive variability the use of the standard deviation or the average range is employed. The standard deviation may be computed by the root-mean-square method from the first fifty pieces taken from the process, or by taking much smaller samples at intervals and computing the standard deviation from the average range. If six standard deviations exceed the total tolerance, scrap or rework, or both, will result.

This procedure may be shortened and used to advantage in many instances by making use of the average range in terms of percentage of the total tolerance rather than following the procedure of computing sigma. The use of average range in terms of per cent of the total tolerance is more direct and can be more readily understood by plant personnel.

This device may be used to advantage in the following instances:

1) To determine when the range of a sample or a series of samples is large with relation to the specification limits.

2) To determine the amount of scrap or rework being produced under (1).

Per Cent of Parts Outside Specifications

*$\bar{R}$	$\bar{\bar{X}}$ — Nominal ±0		±10		±20		±30		±40		±50	
	Above Upper Spec.	Below Lower Spec.	Above Upper Spec.	Below Lower Spec.	Above Upper Spec.	Below Lower Spec.	Above Upper Spec.	Below Lower Spec.	Above Upper Spec.	Below Lower Spec.	Above Upper Spec.	Below Lower Spec.
10									0.99	0.00	50.00	0.00
15							0.09	0.00	6.06	0.00	50.00	0.00
20					0.02	0.00	1.02	0.00	12.30	0.00	50.00	0.00
25			0.01	0.00	0.26	0.00	3.14	0.00	17.26	0.00	50.00	0.00
30			0.09	0.00	1.02	0.00	6.06	0.00	21.83	0.00	50.00	0.00
35	0.04	0.04	0.39	0.00	2.28	0.00	9.12	0.00	25.24	0.00	50.00	0.00
38.77	0.13	0.13	0.80	0.01	3.52	0.00	11.51	0.00	27.43	0.00	50.00	0.00
40	0.18	0.18	1.02	0.02	4.10	0.00	12.30	0.00	28.10	0.00	50.00	0.00
45	0.48	0.48	1.92	0.10	6.00	0.01	15.15	0.00	30.22	0.00	50.00	0.00
50	0.97	0.97	3.07	0.26	8.08	0.05	17.50	0.00	32.06	0.00	50.00	0.00
55	1.70	1.70	4.55	0.55	10.20	0.15	19.77	0.03	33.57	0.01	50.00	0.00
60	2.62	2.62	6.06	0.99	12.30	0.33	21.92	0.10	34.95	0.03	50.00	0.01
65	3.67	3.67	7.64	1.58	14.23	0.62	23.64	0.20	36.02	0.06	50.00	0.03
70	4.85	4.85	9.18	2.33	15.99	1.02	25.30	0.39	36.99	0.14	50.00	0.09
75	6.06	6.06	10.75	3.14	17.36	1.50	26.73	0.66	37.83	0.26	50.00	0.18
80	7.21	7.21	12.10	4.01	19.08	2.17	28.00	0.99	38.52	0.44	50.00	0.35
85	8.53	8.53	13.57	4.95	20.47	2.74	29.20	1.39	39.20	0.68	50.00	0.60
90	9.68	9.68	15.15	6.06	21.92	3.51	30.22	1.92	39.78	0.99	50.00	0.96
95	10.93	10.93	16.35	7.08	23.12	4.27	30.96	2.47	40.32	1.32	50.00	1.39
100	12.30	12.30	17.62	8.23	24.35	5.16	32.10	3.14	40.83	1.83	50.00	1.98

*In per cent of total tolerance.

3) To aid in setting limits beyond which $\bar{\bar{X}}$ should not deviate when $\bar{R}$ is small with relation to the specification limits.

4) To determine when and how much to reset a process that has deviated from nominal.

5) To supplant first and last piece inspection.

6) To aid the patrol inspector on jobs where control charts are not feasible.

With these advantages in mind a table is presented (for samples of 5) which may be used as a ready reference for estimating in any one of the above instances. The range is presented in terms of per cent of the total tolerance so that it will fit any particular specification whether it be ± .0005" or ± 5000 lbs. All one has to do to use the table is to compute $\bar{R}$ ÷ (total tolerance.) The table shows the per cent of parts above and below specification limits. When $\bar{\bar{X}}$ = nominal ± 0 the per cent of parts outside specification will be equally divided above and below, but when $\bar{\bar{X}}$ = nominal ± 10 to ± 50 the larger per cent shown will depend upon whether $\bar{\bar{X}}$ is above or below the nominal. If $\bar{\bar{X}}$ is above the nominal dimension the larger per cent will be above specification and the smaller per cent below, and, conversely, if $\bar{\bar{X}}$ is below the nominal dimension the larger per cent will be below specification and the smaller per cent above.

1) If the average range is 38.77% of the total tolerance, no scrap or rework will result due to an assignable cause provided $\bar{\bar{X}}$ equals the nominal dimension. If the average range exceeds this figure, scrap or rework will result. How much scrap or rework will be shown in (2) below. If the average range is less than 38.77% no scrap or rework will result but how much $\bar{\bar{X}}$ may deviate from nominal under this condition without producing scrap will be shown in (3) below.

2) If, for example, a part is to be turned to a dimension of .500" ± .002", the total tolerance is .004". After 10 or more samples of 5 units each have been taken it is found that $\bar{R}$ equals .0024" or 60% of the total tolerance. Reference

to the table shows that when $\bar{R}$ = 60 and $\bar{\bar{X}}$ equals the nominal dimension, 2.62% of the parts will exceed specification limits, and 2.62% will fall below specification limits. If $\bar{\bar{X}}$ equals .5004" (which is equivalent to a deviation from the nominal of 10% of the total tolerance) 6.06% of the parts will exceed specification limits, and 0.99% will fall below, and if $\bar{\bar{X}}$ equals .5008" (which is equivalent to a deviation from the nominal of 20% of the total tolerance) 12.30% of the parts will exceed specification limits and 0.33% will fall below, etc.

3) If the average range in the example shown above were .0008" or 20% of the total tolerance, reference to the table indicates that no scrap or rework would result if $\bar{\bar{X}}$ remains within .4992" and .5008" ($\bar{\bar{X}}$ = nominal ± 20%) and only 1.02% scrap or rework would result if $\bar{\bar{X}}$ reached as low as .4888" or as high as .5012" ($\bar{\bar{X}}$ = nominal ± 30%). The "break even" point, or the highest or lowest point to which $\bar{\bar{X}}$ could deviate would be .50097" and .49903". This result corresponds with the results one may expect using both 3σ limits and modified control limits.

UCL (3σ) = .50097" + .00046" = .50143"
UCL (mod.) = .50200" − .00057" = .50143"
LCL (3σ) = .49903" − .00046" = .49857"
LCL (mod.) = .49800" + .00057" = .49857"

For obvious reasons the LCL (3σ) for $\bar{\bar{X}}$ = .50097" and the UCL (3σ) for $\bar{\bar{X}}$ = .49903" have been omitted.

4) If a 1% defective can be tolerated during production it will be seen that if $\bar{R}$ is 45% of the total tolerance, $\bar{\bar{X}}$ must at all times be at 0 (or nominal). If the range is 40%, $\bar{\bar{X}}$ may deviate from nominal by ± 10% before a change in the process is in order.

In like manner reference to the table indicates that when $\bar{R}$ equals 30%, 20%, and 10% of the total tolerance the reset point for $\bar{\bar{X}}$ is located at ± 20%, ± 30%, and ± 40% respectively from the nominal in order to assure no more than 1% defective.

The amount the process is to be reset will be determined to a great extent by the nature of the process (as in the case of toolwear) but to take a simple case if it is desired to set the process at the nominal specification the amount of change will be the difference between $\bar{\bar{X}}$ and the nominal.

5) The practice of first and last piece inspection should be discontined wherever possible since examining one piece reveals nothing about variability. A sample of two to six pieces (at the start of the run) depending upon the rate of production and the size of the lot, would enable anyone to predict much more accurately the ability of the process to hold within specification limits for the entire run. Suppose, for example, 100 pieces are to be turned to a dimension of 1.000" ± .002" at a rate of 50 pieces per hour. If the first five pieces exhibit a range of .0015" or less it is much safer to assume the process can hold within specification limits than if only one piece is inspected. Neither would the first piece inspected necessarily reflect the center at which the process is running; it could be a piece at either end of a distribution that is either high or low. Inspection of a convenient number of pieces at the beginning and end of the run plus the use of the table would enable one to predict with a fair degree of accuracy the quality of a short run.

6) The above procedure can be extended to help the patrol inspector where the run is longer than the case cited above but still too short to make use of a control chart. If an inspector has a job with a tolerance of ± .002" and he samples 5 pieces per time interval he should know that under these conditions an average range should not exceed .0015" and no individual value of the range should exceed .0032". In possession of knowledge of what constitutes excessive range he is in a position to warn of impending danger.

For those who are interested in the manner in which a table of this type may be constructed an explanation follows:

If $\bar{R}$ equals 60% of the tolerance, σ = 60 ÷ 2.326 (d_2 for samples of 5) or 25.8% of the total tolerance. To find the percentage of parts within specification limits we must first find the area of the frequency distribution within specification limits in terms of σ. Dividing 50% of the total area by 25.8% gives 1.94. Referring to areas of the normal curve opposite X/σ = 1.94 gives .47381. This means that 47.38% of the parts are within specification limits on one side of the nominal dimension and 2.62% are outside or a total of 5.24% on both sides. The above is based on the assumption that $\bar{\bar{X}}$ equals the nominal dimension. If $\bar{\bar{X}}$ deviates from the nominal dimension by 10% of the total tolerance, the area outside limits on either side must be computed individually.

	Inside	Outside
40/25.8 = 1.55	.439429	.060571
60/25.8 = 2.33	.490097	.009903
	.929526	.070474

This gives 6.06% outside specification limits on one side and 0.99% outside on the other or a total of 7.05. Similarly, if $\bar{\bar{X}}$ deviates from the nominal dimension by 20% of the total tolerance the area outside limits is:

	Inside	Outside
30/25.8 = 1.16	.376976	.123024
70/25.8 = 2.72	.496736	.003264
	.873712	.126288

This gives 12.30% outside specification limits on one side and 0.33% outside on the other side or a total of 12.63%. From this we can see how rapidly the per cent of defects rises as the process deviates from the nominal dimension.

Tables for samples of any other size may be compiled in the same manner by substituting the proper value of d_2 in computing the standard deviation.

A note of warning should accompany the use of these tables. They are based on the assumption that a normal distribution of individual observations and their averages exists which very often is not the case especially in small runs. However, if these limitations are realized and appreciated the tables may be used to advantage in many instances.

An Examination of Data for Casts Made in Basic Open Hearth Furnaces

W. T. HALE

STATISTICAL SECTION, RESEARCH AND DEVELOPMENT DEPARTMENT,
THE UNITED STEEL COMPANIES LTD., SHEFFIELD, ENGLAND

SUMMARY

Object: to find out how the per cent total acids and the weight of lime charged affect the charge to tapping time.

Conclusions

1. That in three of the series of casts a proportion of the variation in the charge to tap time was due to variations in the total lime and total acids.

2. In the remaining three the variations in the charge to tap time could not be explained by variations in total lime and total acids.

3. The variations in the charge to tap time were much greater in some of the series than in the others. In that series where the variation was greatest, least could be explained by regression equations, showing that other factors affecting the variation were present to a greater extent.

4. All the results taken together yielded an estimate of 6½ ± 12½ minutes increase in the charge to tap time per ton of lime, and 6 ± 6 minutes decrease in the charge to tap time per per cent total acids.

THE DATA

consisted of six series of casts:—

1. Series No. 29/2169-2191
Twenty-one casts charged with refined iron.

2. Series No. 29/2193-2212
Eighteen casts charged with basic iron.

3. Series No. 26/8794-8811
Fifteen casts charged with refined iron.

4. Series No. 27/7697-7719
Twenty-one casts charged with basic iron.

5. Series No. E/6199-6230
Twelve casts with anthracite added.

6. Series No. E/6198-6277
Eleven casts with anthracite added.

On each cast three observations were given:

1. A the total lime used for the charge, in tons.
2. B the per cent total acids ($SiO_2 + P_2O_5$) in the tapping slag.
3. C the time lapse from starting to charge to tapping, in hours.

THE PROBLEM

to find:

1. How the total lime affects the charge to tapping time if the per cent acids did not change.
2. How the per cent total acids affect the charge to tapping time if the total time used remained constant.

RESULTS

A statistical treatment of the data is given in an appendix for the benefit of readers who may wish to study the statistical analyses from which the following results were taken.

For the whole set of data:

If the per cent total acids did not change, one ton increase in the lime would increase the charge to tap time by 6½±12½ minutes (1 in 40 limits.)

If the weight of lime remained constant, an increase of 1 per cent in the total acids would decrease the charge to tap time by 6±6 minutes.

For the individual series of casts the results are summarized in Table 1. The coefficients measuring the increase in charge to tap time per ton of lime were tested for signifcance from zero. Those marked (*) were different from zero.
The coefficients measuring the decrease in the charge to tap time per cent total acids were tested for difference from zero. Those marked (*) were significantly different.

1. In the series 29/2169-2191 (refined iron) 30 per cent of the variation in the charge to tap time was due to variation in the weight of lime and the per cent total acid. The relationship was:—

   One ton increase in the lime increased the time by 34±25 mins.

   One per cent increase in the acids decreased the time by 12±9 mins.

2. In the series 27/7697-7719 (basic iron) 30 per cent of the variation in charge to tap time could be explained by a decrease of 13±9 mins. per cent total acids.

3. In the series E/6198-6227 (without anthracite) 50 per cent of the variation in charge to tap time could be explained by an increase of 32±23 mins. per ton of lime.

4. In the remaining three series, variations in the weight of lime and the per cent total acids did not account for any of the variation in the charge to tap time.

5. For the two series 29/2193-2212 (basic iron) and 26/8794-8811 (refined iron) the variations in the charge to tap time were greater than in the others. Furthermore none of this variation could be attributed to the variation in lime and acids. It indicated that there were other factors influencing the charge to tap time which were present to a greater extent in these two series.

	1	2	3	4	5	6
Series No.	29/2169 —2191	29/2193 —2212	26/8794 —8811	27/7697 —7719	E/6199 —6230	E/6198 —6227
No. of casts	21	18	15	21	12	11
Description	Refined Iron	Basic Iron	Refined Iron	Basic Iron	With Anthra.	Without Anthra.
Average						
Charge to tap time (hrs.)	11.36	11.84	12.36	10.63	10.38	10.05
Average Lime (tons)	6.06	7.32	6.32	7.33	5.76	5.59
Average % Acids	16.59	18.03	16.29	16.87	16.94	16.36
Variance of						
1. Charge to tap time (hrs.)	1.07	1.98	1.66	0.75	0.48	0.40
2. Av. Lime (tons)	1.19	2.16	0.81	0.63	1.46	0.75
3. % Acids	8.43	4.19	4.75	5.22	6.42	2.88
Increase in charge to tap time (mins.) per ton lime. Acids constant. (1 in 40 limits)	34±25*	3±33	—13±53	—5±26	—13±29	32±23*
Decrease in charge to tap time (mins.) per % total acids. Lime contsant. (1 in 40 limits)	12±9*	1±23	—4±22	13±9*	—2±14	—5±12
% of the Variance of charge to tap time explained by the regression.	30%	0%	0%	30%	0%	50%

TABLE I

The coefficients measuring the increase in charge to tap time per ton of lime were tested for significance from zero. Those marked (*) were different from zero.
The coefficients measuring the decrease in the charge to tap time per per cent total acids were tested for difference from zero. Those marked (*) were significantly different.

STATISTICAL APPENDIX

The **data** consisted of six series of casts each series being made under different conditions.
On each cast three factors were given:
A the total lime used for the charge (in tons)
B the per cent total acids
C the time lapse from starting to charge to tapping (in hours)
The **problem** was to find out how the per cent total acids and the total lime affect the charge to tapping time.
The **method** aimed at expressing the relationship between the three factors by means of a regression equation of the form:

$$C-\overline{C}=a\,(A-\overline{A})+b\,(B-\overline{B})$$

where:
A denotes the total lime in tons,
B denotes the per cent total acids,
C denotes the charge to tap time in hours,
$\overline{A}$, $\overline{B}$, $\overline{C}$, denotes average values.
The coefficient "a" measures the increase in the charge to tap time (hrs) per ton of lime charged if the per cent total acids remained constant.
The coefficient "b" measures the change in the charge to tap time per per cent total acids if the weight of lime were unchanged.
Such equations were obtained for each series of casts separately. They are given in Table II.
Each coefficient was tested by transforming to the Student's t distribution, and testing the significance of the t. The coefficients marked (*) were significant.
The equations show that:

For the series 29/2169-2191 (Refined Iron)

1. An increase in the total lime of 1 ton increases the charge to tap time by 0.57 hrs., (34 mins.).
2. A decrease of 1% in the total acids increases the charge to tap time by 0.21 hrs., (12 mins.).

For the series of 29/7697-7719 (Basic Iron)

1. A decrease of 1% in the total acids increases the charge to tap time by 0.22 hrs., (13 mins.).

For the series E/6198-6227 (Without Anthracite)

1. An increase of 1 ton in the total lime increases the charge to tap time by 0.53 hrs., (32 mins.).

The coefficients "a" and "b" are estimates only, and have sampling variances. Using the t distribution, the 1 in 40 limits within which the true value of the coefficients lies were evaluated. These are quoted in Table III.

If the "a" coefficients were tested for difference from any value within the range 9 minutes to 16 minutes, none would have been different on the 5 per cent level.

Similarly if the "b" coefficients measuring the decrease in time per

TABLE II

Series Nos.	Description	Regression Equation
29/2169—2191	Refined Iron	C—11.36—0.57* (A—6.06)—0.21* (B—16.59)
29/2193—2212	Basic Iron	C—11.84—0.06 (A—7.32)—0.02 (B—18.03)
26/8794—8811	Refined Iron	C—12.36—0.22 (A—6.32)+0.06 (B—16.29)
27/7697—7719	Basic Iron	C—10.63—0.08 (A—7.33)—0.22* (B—16.87)
E/6199—6230	With Anthracite	C—10.38—0.22 (A—5.76)—0.04 (B—16.94)
E/6198—6227	Without Anthracite	C—10.05—0.53* (A—5.59)—0.09 (B—16.36)

TABLE III

Series No.	Coefficient a. Increase in charge to tap time (hrs.) per ton lime	Coefficient b. Decrease in charge to tap time (hrs.) per % total acids
1. 29/2169-2191 refined iron	34±25 i.e. 9 to 59 mins.	12± 9 i.e. 3 to 21 mins.
2. 29/2193-2212 basic iron	3±33 i.e. —30 to 36 mins.	1±23 i.e. —22 to 24 mins.
3. 26/8794-8811 refined iron	—13±53 i.e. —66 to +40 mins.	—4±22 i.e. —26 to 18 mins.
4. 27/7697-7719 basic iron	—5±26 i.e. —31 to 21 mins.	13± 9 i.e. 4 to 22 mins.
5. E/6199-6230 with anthracite	—13±29 i.e. —42 to +16 mins.	—2±14 i.e. —16 to 12 mins.
6. E/6198-6227 without anthracite	32±23 i.e. 9 to 55 mins.	—5±12 i.e. —17 to 7 mins.

per cent total acids were tested for difference from any value within the range 4 to 7 minutes, none would have been different on the 5% level.

Further light may be shown on these regression lines by finding out how much of the variation in the charge to tap time may be accounted for by the variations in in the weight of lime, and the per cent total acids.

For each series the total variation in the charge to tap time was divided into:

1. A part due to fitting of the regression equation.
2. A part left over after fitting the equation.

These analyses are shown in Table IV.

TABLE IV

	Series No. 29/2169-2191 Refined Iron		Series No. 29/2193-2212 Basic Iron		Series No. 26/8794-8811 Refined Iron	
Nature of Variation	D.F.	Mean Square	D.F.	Mean Square	D.F.	Mean Square
For fitting the regression	2	4.09*	2	0.06	2	0.44
After fitting the regression	18	0.74	15	2.24	12	1.86
Total	20	1.07	17	1.98	14	1.66

	Series No. 27/7697-7719 Basic Iron		Series No. E/6199-6230 With Anthracite		Series No. E/6198-6227 Without Anthracite	
Nature of Variation	D.F.	Mean Square	D.F.	Mean Square	D.F.	Mean Square
For fitting the regression	2	2.75*	2	0.27	2	1.14*
After fitting the regression	18	0.52	9	0.52	8	0.21
Total	20	0.75	11	0.48	10	0.40

The variance ratio test was used to compare the mean squares due to the fitting of the line with the mean squares left over after fitting the line. Those marked * were significant. This indicated, as before, that in the case of series nos. 29/2169-2191 (Refined Iron), 27/7697-7719 (Basic Iron), E/6198-6227 (Without Anthracite) the equations expressed a real relationship.

The table also shows how much of the total variation remains after fitting the regression line. In the case of the three series of casts dealt with, the variation is reduced to 70%, 70%, and 50% respectively, whereas for the other three series it was not reduced.

The number of casts in each series was relatively small and it was not surprising, therefore, that the coefficients "a" and "b" were ill-defined.

Accordingly, the data were grouped together to give an estimate of these coefficients based on a greater number of casts. Allowance was made for the fact that the average levels of the charge to tap time, the weight of lime, and the per cent total acids were different for each series of casts.

The estimates obtained were:—

1. An increase of 6½ minutes in the charge to tap time per ton of lime, the percentage acids being constant. After transforming to the Student's t distribution and testing the significance, it was found that this estimate was not significantly different from zero. The 1 in 40 limits within which the coefficient would be said to lie were 6½±12½ mins. i.e. −6 to +19 minutes.
2. A decrease of 6 minutes in the charge to tap time per per cent total acids, the weight of lime being constant. This value was different from zero. The 1 in 40 limits within which the true value should lie were 6±6 mins. i.e. 0 to 12 mins.

These estimates are more closely defined than were those for the individual series. Before they were accepted it was necessary to test whether this single regression equation was as trustworthy as the separate equations to each series of casts. This was done by analysing the variance of the charge to tap time within the series of casts into:

1. A part that was accounted for by the single regression equation.
2. A part that showed how far the separate equations for each series differed from the single equation.
3. The part that was not accounted for by fitting regression equations (Residual).

This is shown in Table V.

The variance ratio test was used to compare the mean squares of column 4 in Table V, and to decide whether they had any significance.

The deviations of the six separate equations from the single equation compared with the residual variation was not significant, and indicated that the single equation was as good as the average of the six separate equations.

TABLE V

Components of Variation	S. Sq's	D.F.	M.S.
For fitting single regressions	4.55	2	2.28
For deviations of the 6 separate regressions from the single regression	12.94	10	1.29
Total = For fitting the 6 separate regressions	17.49	12	1.46
Residual	85.06	80	1.06
Total = Within Groups	102.55	92	1.11

However, when the variances attributed to the single regression equations or to the six separate regressions were tested against the residual, neither was significant. This indicates that on the average the six separate regression equations did not portray a close relationship between the charge to tap time and the weight of lime and the per cent total acids.

This was probably due to the fact that different levels of control had been exercised over the different series. The variation of the charge to tap time expressed as a variance for each of the series separately was as shown in the totals row of Table IV. When tested by the Bartlett's test they were not homogeneous. This indicated that series no. 29/2193-2212 (Basic Iron) had a greater variation in charge to tap time, and series no. E/6199-6230 (With Anthracite) and E/6198-6227 (Without Anthracite) had a smaller variation than the others.

Further, when the variances left over, after fitting the regression lines, were compared by Bartlett's test they showed even greater differences. The variance of series no. 29/2193-2212 (Basic Iron) had been increased, and that of E/6198-6227 (Without Anthracite) was further decreased.

These two taken together show that the series no. 29/2193-2212 had a greater variation in the charge to tap time due to a cause other than the variation in the weight of lime and the per cent total acids; whereas the much smaller variation in series no. E/6198-6227 was largely due to variation of the weight of lime and the per cent acids.

A summary of the results shows:

1. That in three of the series of casts a proportion of the variation in the charge to tap time was due to variations in the total lime and total acids.
2. In the remaining three the variations in the charge to tap time could not be explained by variations in total lime and total acids.
3. The variations in the charge to tap time were much greater in some of the series than in the others. In that series where the variation was greatest, least could be explained by regression equations showing that other factors affecting the variation were present to a greater extent.
4. All the results taken together yield an estimate of 6½±12½ minutes increase in the charge to tap time per ton of lime, and 6±6 minutes decrease in the charge to tap time per per cent total acids.

Management Needs Quality Control

GEORGE J. MEYERS, JR.

WATERTOWN PLANT, MANNING, MAXWELL & MOORE, INC.

Quality is to a product what character is to a person. All of the eminent trademarks in industry stand on pedestals of quality. Trademarks and renowned names are worth millions in credit, goodwill and sales. Even when companies go through drastic changes in ownership the name and trademark of the company are either retained or are the last items to be relinquished.

Quality and Quality Control

The single term "Quality" is associated with the idea of a good

product or a good service. The words "Quality Control," however, add the consideration of continuity to that of initial goodness. Continuity of good quality carries beyond the purchase of a product to its low-cost maintenance, to its ease of repair, to its long life, and even to the confidence of the buyer in eventually replacing the product with another high quality item of the same make. Continued good quality, or "Quality Control" as it should be called, is a positive earmark of the successful manufacturer. Hence, controlled quality sells the buyer on both the product and the concern.

Quality Control can be achieved only in successful concerns having progressive and forward looking leaders. Under such leadership is found the knowledge, courage, and foresightedness to use adequate resources for planning ahead so that operations will function on a continuous basis. The essence of Quality Control is solving this problem of continuity. If continuity of operations exists in a business, Quality Control can thrive. It is often time alone which washes out of existence concerns whose scope of operations is too limited in either breadth or continuity to support Quality Control. Time, therefore, is the first sieve through which enterprises are run in determining those which may be considered successful and fertile for the growth of Quality Control.

Time is also needed to prove the excellence of a product and a service. Product goodness alone is like quality goodness without continuity. The good product and service open the door to consumer interest, but the success of the concern adds the element of confidence. Quality in the product may be at high cost. It may be that the price of quality is so high that subsequent products of the same make would have to suffer. In many cases concerns have priced themselves out of the market by passing to the consumer high quality at too high a cost. Quality Control tends to correct such a situation because Quality Control is inherently an efficent manufacturing procedure which reduces the necessity for extra safety factors in design. Of course, costly designs alone can more than offset the gains from Quality Control. This fact merely emphasizes the need for experience and proven success in the field of application. From the point of view of the consumer, however, it is sufficient to say that reliability of product and success of the maker over sufficient time determine the quality rating and reputation of the concern.

From the consumers' or investors' point of view the proving of the existence of Quality Control and business success or the detection of of lack of Quality Control and a trend toward failure is likely to be a slow process. Within the enterprise the cycle is much shorter and cause and effect are more apparent. An examination of the internal operations of an enterprise demonstrates that the attaining of continuity in quality opens the door to benefits which make for success. Conversely, decisions leading to lack of continuity quite swiftly lead to confusion, the forerunner of failure. It is easy to watch the success of sections of the operations rise or fall in proportion to the degree of Quality Control maintained therein. In this case observations during short passages of time consisting of only a few days, or a few weeks, or a few months, are sufficient to show the effects of good Quailty Control or the lack thereof.

Take for example the concern which buys inventions from inventors without following these ininventions into the field of application and modifying the inventions as problems in application are found. Such a concern may have a very fine product that is a leader in its field but in very short order the test of usage proves that certain qualifications are needed. Therefore, the new product falls into disrepute not because it was poor in quality when first invented, but because it did not meet the test of continuity in the hands of the consuming public.

Furthermore, such concerns in hopping from product to product are taking long chances in different fields rather than building up a know-how in a single field. A few bad bets on unsatisfactory products would spoil the record and destroy the feeling of continuity associated with good Quality Control. In such a case the time cycle in which appears the results of the rise and fall of quality would be likely to be between six and eighteen months in length.

Where life is an important factor in the success of a product, continuity of quality can easily be lost through making design changes without adequate life testing. This is grasping at good quality but not controlling quality. Since a percentage of grasps are likely to be wild and result in wrong decisions it is usually within a matter of months that trouble from the field adds to the work of the engineering staff and time has to be wasted in emergency decisions or in making up for lost time in the purchase of more costly test apparatus than would otherwise have been needed.

At some time or other most manufacturers have had the experience of seeing one supervisor change a process to correct trouble, followed by a second supervisor making a second change, followed by the first supervisor changing partially back again, and then the second supervisor making an additional change, with the result that the job became pretty well botched up. In one instance this happened with four individuals all making changes. In four weeks the operators building the apparatus became so confused that they were not sure to which design they were working, they were putting in scrapped parts along with good parts, and the appearance of the working area was anything but indicative of good housekeeping. In this case Quality Control was rescued by clearing all the changes through one person and by removing all rejected material from the operating area.

Another somewhat similar problem in which lack of Quality Control tangles up management is that where unauthorized persons change specifications or where no specifications exist. In this case the last person who talks to the opertor sets the quality. Usually the quality so set has very unexpected characteristics. The operator ends by doing the job in whatever way he wants to, and after a few months, when the show-down comes, it is found that no one is to blame except that the operator failed to possess the judgment of Solomon in deciding which advice

to follow of that given by various important executives.

Finally, we are all familiar with the control of quality which has been lost through failure to identify and store properly materials or tools, or gauges, or parts. In this case the lack of control comes through the lack of a systematized business-like procedure for handling such matters.

In all of these very common types of failure to maintain the continuity required by Quality Control, trouble occurs very soon after the element of control is discontinued. The Plant's Management can quickly see such problems; they are also soon known to the Sales Department, but the public, as a whole, may not appreciate that they exist until so many of them accumulate that the claims of advertising are proven to be false.

Two other kinds of lack of Quality Control which are extremely serious do not follow the short cycles of the instances cited above. Both are insidious forms of the lack of quality continuity which may go on under the eyes of management for a long time without those concerned understanding the basic trouble. One is the absence of quality performance or inspection records, or of the records being completely meaningless. The other is that operators may be getting by without having a full appreciation of precisely what is happening as the result of their efforts to make a part or fabricate an assembly. The symptom of these related maladies is a sort of hang-dog attitude toward quality. The operators individually will claim they they are most anxious to get out good quality work. Since their failure to do so is on account of causes unknown they rightly think that management's exhortation to them on the subject of quality is weak. Subconsciously the worker senses the lack of additional assistance or information needed to show how the quality can be achieved.

The tone of an organization where there are no records of past performance and where there is no knowledge of current process results is certain to be poor. Furthermore, the general effort required within the organization to get simple things accomplished relative to either quality or production is likely to be excessive in comparison to the results desired or achieved. The correction in this instance is one which cannot be made quickly, because in general it requires much education and the introduction of a sense of accomplishment within the organization.

The above examples were given in order to show: first, that the causes for the lack of Quality Control are generally of the variety quite familiar to everyone; secondly, the problem of maintaining continuity, which is necessary in Quality Control, is the exact same problem as achieving good management. When the continuity exists that is required by Quality Control, good management practices follow automatically and in turn generate success for the enterprise. Let us consider the logical consequences of having good Quality Control in engineering and manufacturing.

Quality Control of Operations

Quality Control forces the engineer to depart from sporadic inventivenes and coordinate inventiveness with field experience. Hence, design and developments follow the requirements of the trade, and the net result is continuity of quality in engineering, a steady and sound expansion of the engineering field, and general success for the engineering development staff.

The maintenance of Quality Control in the establishment of firm specifications automatically creates that foundation which eliminates unnecessary production, engineering and factory trouble shooting, and unnecessary factory argument, thereby gaining economy of effort for both the engineering staff and the factory managerial staff.

By having business-like operations in the control of men, materials and equipment, one not only avoids using the wrong tools or the wrong equipment but a g a i n, through this element of Quality Control, one can economize on manpower and effort so that management can concentrate on the exceptional problems of operations instead of on the standard problems of operations, thereby adding one of the major ear-marks of success.

In the narrower sense, Quality Control in the shop results in the various operators knowing what the processes can do and are doing, and what the recent results have been. Quality Control emphasizes the common goal ahead and there is automatically introduced into the organization the sense of understanding and of accomplishment which, supported by good leadership, makes for success.

The preceding outline indicates that Quality Control in its broader aspects is a thing which has long been done in the past, possibly, however, not under the name, "Quality Control." Also indicated is the need for looking at the overall Quality Control picture. Otherwise, it will usually be found that there are gaps of bad quality performance in what might otherwise be a wide continuous spectrum of efficient operations. In successful Quality Control activity it is first necessary to consider all of the bands of the spectrum of operations and then to examine each band with the particular techniques applicable to the study of that band.

The first check for each spot in the spectrum of operations is to examine as to whether or not the product at that point reflects both quality and continuity of quality. These data may be in the form of tabulations resulting from practical business procedures established for operating the job. They may be in the form of plotted curves or distribution charts. The data may include calculated limit lines or other special statistics to show the boundary conditions between good and bad or normal and abnormal. In getting the facts it will, therefore, be seen that one depends first and primarily on practical business procedures which are as old as enterprise itself. In regard to the second item above, it will be noted that engineers have made curves and drawn distribution charts for many years. The new element of interest to management is the introdutcion of the use of scientifically set limit lines or other statistical techniques to tell whether the observed result is usual or unusual.

After reviewing the quality facts at each stage of the operations it is next necessary to take such action as is needed in order to obtain Quality Control. Such action may: (a) follow standard good business procedure; (b) emphasize

or establish the continuity of procedures; (c) call for the use of distribution charts for explaining results; and (d) make use of scientific sampling instead of haphazard sampling in sifting out defective material.

As in the case of getting the facts, it is to be noted that taking the corrective action involves, first of all, time honored good business practices combined with publicity or informative programs directed toward conserving, stimulating, and directing human effort. However, there are several important supporting statistical techniques.

The first new element introduced is the use of distribution charts in the shop whereas heretofore it has been customary more or less to confine the use of such data to the office of the technical staff. The second new element is the idea of establishing inspection procedures based on principles which guarantee specific quality levels. The third new element involves guiding operations by means of statistical yardsticks based on the conception of an always varying operation to be controlled within specified limits. It is to be noted that the carrying out of corrective action is based primarily on standard good business practice plus the use of statistics at the shop level. Statistical Quality Control is the name given to the operations set in motion and guided by either statistical calculations as in the case of inspection, or the statistical concept as in the analyzing of a distribution chart of a cutting operation in order to adjust a machine tool.

Statistics alone will not guarantee Quality Control any more than using the slide rule will guarantee engineering proficiency. On the other hand, the statistical concept can greatly aid a practical person in making a sensible decision in the shortest length of time, where development engineering or shop Quality Control operations are concerned. Although much has recently been published regarding the application of statistics to Quality Control, the statistical theory is widely used in practically all fields where there is considerable variation in data. Possibly the reason for the sudden interest in it in regard to engineering and manufacturing is that by tradition in these two fields it has been customary to think of parts as either being made all alike or as being different due to outstanding causes which will be corrected "tomorrow." Now it is being realized that variation always exists, that it must be taken into account, and that only a small portion of this variation can be traced to causes that can easily be corrected "tomorrow."

Quality Control Requires Effort

One might be led to infer that inasmuch as Quality Control, although benefitted by statistical techniques, is based primarily on common sense practices it should in general be an item efficiently carried on without more than the normal amount of effort. On the contrary, actual practice shows that it is not easy to maintain Quality Control. The reasons for this are many. If the layout of a plant is not correct it may not be possible to supervise efficiently the quality level of a group of personnel without having a very high ratio of inspection manpower to direct labor manpower. Such would be the case of a shop divided into many small sub-divisions separated from each other and located, possibly, on many different floor levels.

A very common difficulty is that there may not be enough room or facilities to get out the amount of production required. Hence, good business procedures in handling men, materials and equipment are practically impossible. In order to control quality under such conditions the staff has to be extremely large and uneconomical. In such instances, either consciously or unconsciously, the management is likely to sense that the cost of quality is exceedingly high. Then follows an unintentional willingness to let the quality slide. In the long run this would of course lead to serious difficulties for the enterprise.

Another cause for it being difficult to establish a high quality level is that the amount of business as compared to the amount of tooling may be such that a given job, of itself, would not be able to pay the cost of new tools or duplicate tools needed in order to obtain better quality. In this case one can still have his quality economically, but in order to do it he must make his tool corrections at replacement. If this should be done on the basis of job lot operations, the time required would be many months, and over such a period of time it would be quite natural to have lapses of memory regarding quality standards. Not only must the tools be slowly replaced, but as the new tools are brought in there must be better provision for taking care of them and for seeing that they are maintained in a more satisfactory condition than was the case with the superseded tools. Quality Control under such circumstances requires that the need for continuity of quality be kept firmly in mind over long periods of time.

Quality Control is likely to be unpopular at some part of the plant's operations because, as a result of Quality Control, skeletons have a way of being dumped out of the closet. This always seems to happen at the most inconvenient and embarrassing moments. Even the Quality Control men cannot tell when this will happen. The very human desire to push the skeleton back in the closet again as quickly as possible so that he can later be let out one bone at a time tends to retard Quality Control operations. In other words, a certain amount of raw managerial courage is needed in order to accept the fact that a condition is bad and to set about correcting it without pretending it is not bad.

Lack of close liaison between different sections of an organization makes it difficult at times to maintain Quality Control. This is due to there being a reciprocated lack of understanding as to the significance of each group's problems. For example, engineering and sales have to work very closely together in order that field quality problems will receive due emphasis in the design department and in turn that a quality improvement in design is fully appreciated by the sales force.

Finally, Quality Control depends upon the faithful continuance of many important routines throughout the organization. Those directly in charge of the routines may not realize their importance as related to other operations. Consequently, there is a tendency, particularly with changes in personnel, to economize either by introducing new routines without due consideration as to what the effect may be else-

where or by letting the existing routines slowly die out.

In order to prevent this and keep that coordination throughout the whole enterprise which is needed for Quality Control, it is generally necessary to have an overall coordinator. This is a difficult administrative job since the person who is the overall Quality Coordinator or Quality Manager has to understand a great deal about the detailed operations of the plant, he never sees any but the seamy side of operations, he is in a position of being forced to say "no" to practically everybody in the organization nearly all of the time, and his decisions are frequently very important and far reaching. Many concerns have recently appointed Quality Managers. In some companies these managers may report to a Works Manager or some other high company official of the Line Organization type. In some companies the top man in Quality Control may report to the Chief of Engineering. Engineers are generally quality minded but frequently are not sufficiently production minded, so that undoubtedly for this reason there are instances where Quality Control has proven unsuccessful as part of the responsibilities of the head of Engineering. From an overall point of view, inasmuch as Quality Control affects both engineering and manufacturing, it would seem best that the guiding person in Quality Control be independent of both engineering and manufacturing and be a man of sufficient caliber to make important decisions affecting either engineering or production policies.

Conclusion

Management needs Quality Control. It is on the foundation of quality that eminently successful enterprises build the consumer's desire for their products. From an external point of view, the full measure of a company's Quality Control program may not be seen for a long time, depending on the nature of the product, the support of the advertising program and how long it takes the consumer to prove that quality does or does not exist. If we look within the plant's walls, we can, however, observe that efficient operations and good Quality Control go hand in hand and that the gains to be obtained from good Quality Control are very rapidly realized.

The technique of Quality Control is not mysterious but is founded on common sense. The statistical concept of Quality Control is of great value to the man carrying out Quality Control operations. However, it is only one important part of the Quality Control program and is not an end in itself. For many reasons which are psychological or for false economy, Quality Control tends to diminish unless watched carefully and given support of high company policy.

For Quality Control to succeed it is necessary that it be in the hands of a man able to make important decisions from the viewpoint of top management. This man and his assistants should also fully understand the details of operations so that quality can be controlled from engineering through manufacturing to field application, or from the birth of the product until it wears out of ripe old age and the customer is ready to buy a replacement from the same maker.

AMERICAN SOCIETY NEWS

CONSTITUTIONAL AMENDMENT REGARDING OFFICERS' TERMS

In a letter to all members of the Society, dated 14 March, 1947, the Executive Secretary submitted a constitutional amendment which would permit the President and Vice-President of the Society to hold the same office for not more than two successive terms. This amendment had been proposed by the Committee on Constitution and By Laws and had been endorsed by a number of other members of the Society.

The Executive Secretary's letter enclosed a postal ballot for action with regard to this proposed amendment, and fixed 20 April, 1947 as the closing date for the balloting.

Of the 1698 eligible ballots mailed out by the Executive Secretary, he now reports that 1,099 valid ones were returned prior to the closing date. Of these, 1,046 favored the amendment and 53 opposed it. The Constitution therefore stands amended as proposed.

PRELIMINARY NOTICE OF ANNUAL MEETING

In accordance with the provisions of its Constitution, the Society's Annual Meeting will be held in New York City on Friday, 27 June, 1947. Official notice of the exact time and place for the meeting will be mailed to each member of the Society by the Executive Secretary prior to 27 May.

The notice for the Annual Meeting will be accompanied by an Official Ballot listing all eligible candidates for officers of the Society for the fiscal year 1947-48. Eligible candidates include those proposed by the Nominating Committee and any independent nominations made by petition in accordance with the provisions of the Constitution.

In addition to the ballot for Officers, the notice for the Annual Meeting will be accompanied by a copy of the new Constitution proposed for consideration at that Meeting, and an Official Ballot to be used in voting for or against such adoption.

Members may vote for Officers, and for or against adoption of the proposed new Constitution, either in person at the Annual Meeting or by marking the Official Ballots and mailing them to reach the Executive Secretary in advance of that meeting. Members who cannot attend the Annual Meeting are urged to vote by mail, so that the decisions reached will represent the expressed wish of as large a proportion of the membership as possible.

NOMINATING COMMITTEE NOMINATIONS FOR SOCIETY OFFICERS FOR 1947-1948

The Executive Secretary reports that he has received from the Nominating Committee the following nominations for Society Officers for the year 1947-48:

For President: George D. Edwards

For Vice-President: Fred J. Halton, Jr.

For Executive Secretary: Ralph E. Wareham

For Treasurer: Alfred L. Davis

The Official Ballot for election of officers will include the above names and any others sent to the Executive Secretary by local Sections as prescribed in Article VI, Section 2 of the Constitution and By Laws.

NEW CONSTITUTION

The March issue of Industrial Quality Control carried substantial information with regard to certain proposals as to dues and grades of membership to be incorporated in a new constitution for the Society.

The Committee on Constitution and By Laws has since completed a draft of an entire new constitution including the dues and membership grade proposals mentioned above, and has submitted this complete draft to the Executive Committee with its endorsement.

On 26 April, the Executive Committee, the Committee on Professional Ethics and Qualifications, and the Committee on Constitution and By Laws met in joint session in New York City. These three Committees studied the Constitution and By Laws Committee's draft constitution, section by section, and agreed on a wording for each section which they were willing unanimously to recommend to the Society for adoption. This wording, section by section, has now been incorporated in a new complete draft constitution for the Society, which differs not at all in plan and principles, and relatively little in detail, from the draft as originally recommended by the Committee on Constitution and By Laws.

This new draft constitution will be submitted to the membership for consideration and possible adoption in the postal ballot closing at the Annual Meeting on 27 June, as outlined in the Preliminary Notice for that meeting carried in this issue of Industrial Quality Control.

The proposed new constitution is an operational document in every respect. While it introduces a number of customs and procedures which are new to the Society, all of them are old and tried so far as other societies are concerned. Each of them has been included only after much thorough discussion and consideration by Committee members representing all of the diversity found in the membership of the Society. The procedures included are calculated to relieve the Society's Officers from many of the details with which they have been burdened during the past year.

Altogether, the Committee members who have been concerned with formulation of the draft which is being submitted to the membership, are uniformly agreed that it is undoubtedly the best constitution which the Society could hope to obtain, and that it is in fact almost a model document from an operational point of view.

The Committee on Constitution and By Laws, the Committee on Professional Ethics and Qualifications, and the Executive Committee of the Board of Directors of the Society, have each passed unanimously a resolution endorsing the proposed constitution and urging its adoption by the membership of the Society.

It is hoped that all members who cannot attend the Annual Meeting in person will make use of the postal ballot, so that the decision reached with regard to adoption of the proposed constitution will represent the expressed wish of as large a proportion of the membership as possible.

PAYMENT OF DUES FOR 1947-1948

The March issue of Industrial Quality Control outlined at some length the considerations which led up to establishment of the dues scales which are included in the proposed new constitution. Briefly these included arrangements:

a. to limit the qualification requirements for the Member grade to:

   1. a minimum age of 21 years, and
   2. an interest in quality control,

   so that corporate membership in the Society would be available to relatively young and inexperienced men;

b. to hold to a minimum the necessary increase ($1.00) in the dues for the Member grade, so that younger men would not find membership in the Society too great a tax on their resources;

c. to permit a gradual approach (over a period of several years) to the ultimate qualification requirements for the Senior Member grade, so that practically all but the youngest present members would be eligible for this grade immediately;

d. to thus limit the qualification requirements for the Senior Member grade for the fiscal year 1947-48 to:

   1. a minimum age of 24 years, and
   2. a minimum of 2 years' experience in quality control or inspection engineering work or in the teaching of such subjects in a school of college grade;

e. to urge all eligible members to transfer to the Senior Member grade immediately, since those continuing to pay only Member grade dues would not be carrying their fair proportion of the cost of maintaining and operating the Society.

While none of the arrangements mentioned above, and none of the new dues scales, will become effective until 1 July, 1947, and then only if the proposed new constitution is duly adopted, it appears advisable to begin accepting dues payments for the fiscal year 1947-48 only on the basis provided for in the proposed new constitution.

The Society will hence accept hereafter, from secretaries of Sections, certifications that applicants for membership in the American Society are Section members in good standing and meet the qualification requirements for the Member grade as outlined under **a**.

above. When accompanied by remittance of $4.00, such certification will automatically enroll the applicant as a Member of the American Society for the fiscal year 1947-48.

It is felt that the 1947-48 qualification requirements for the Senior Member grade are so simple and straight forward that they also can be adequately administered by Section secretaries during the period until the Examining Committee is duly constituted and ready to function.

On this basis, the Society will hence accept until further notice, from secretaries of Sections, certifications that American Society members or prospective members are Section members in good standing and meet the 1947-48 qualification requirements for the Senior Member grade as outlined under **d.** above. When accompanied by remittance of $8.00, such certification will automatically enroll the member or applicant as a Senior Member of the American Society for 1947-48, provided the proposed new constitution is duly adopted.

Corresponding with the above arrangements, and pending completion of new Application Blanks, Transfer Blanks, etc., the Executive Secretary will accept "direct applications" for the Member grade on the old blanks when accompanied by remittance of $5.00 and personal certification by the applicant that he meets the qualification requirements outlined under **a.** above.

Similarly, the Executive Secretary will accept, until further notice, "direct applications" for the Senior Member grade when accompanied by remittance of $10.00 and personal certification that the applicant meets the 1947-48 qualification requirements for the Senior Member grade as outlined under **d.** above. Such applications must also be accompanied however, by a statement from the applicant outlining the character of the experience claimed and the circumstances under which it was acquired, and Senior Membership will not be effective until the application has been accepted by the Executive Secretary.

No applications for the Fellow grade, and no dues payments therefore, will be accepted until the Examining Committee is duly constituted and is ready to function.

It is sincerely hoped that all present members of the Society who will be eligible to transfer to the Senior Member grade under **d.** above, will consider seriously the implications of **e.** above and will take the necesssary steps promptly to effect their transfer. The entire dues structure in the new constitution contemplates a substantial proportion of the membership in the Senior Member grade.

Failure of the membership to recognize and discharge its responsibility in this matter will necessitate steps to increase still further the dues for the Member grade. This would in turn drive from the Society many younger men unable to meet the higher dues, — a result which would defeat one of the main objectives of the Society, and which could not fail, in the long run, to react to the disadvantage of the entire membership.

FOUNDING MEMBERSHIP BOOKS CLOSE

With the end of the Society's first full fiscal year on 30 June, 1947, the Founding class of membership will no longer be available.

The 1946-47 Year Book contains a separate listing of 183 Founding Members. In addition, the name of each Founding Member is identified by a star in the complete catalogue of members.

A number of additional Founding Members have been enrolled since the 1946-47 Year Book went to press, and it is hoped that a further large number of members will take advantage of the privilege to enroll during the few weeks longer that the opportunity will remain open.

The 1947-48 Year Book will contain a separate listing of the entire Founding Membership class, and the name of each such member will be starred in the catalogue. Subsequent year-books will continue to identify Founding Members by stars in the catalogue.

Members who have not already done so, are urged to evidence their support for the Society in this critical period of its development, by sending five dollars or more immediately to:

Mr. R. E. Wareham,
Executive Secretary
305 East 43rd Street
New York 17, N. Y.

All such remittances received before 30 June, 1947 will automatically enroll the donor as a Founding Member.

DR. BRUMBAUGH RESIGNS AS CHAIRMAN

At the Executive Committee meeting on 27 April, Dr. Martin Brumbaugh tendered his resignation as Chairman of the Editoral Board to be effective 30 June. He explained the necessity for this step by pointing out the magnitude of the change involved for him in transferring suddenly from academic to industrial work, and he indicated that he felt it absolutely essential that he be free to devote himself exclusively to his new work for the present.

The Executive Committee was able to find no alternative to acceptance of Dr. Brumbaugh's resignation, and it counted itself fortunate in persuading him to continue as a member of the Editorial Board even though he would no longer be its Chairman. This latter arrangement is with Dr. Brumbaugh's stipulation that his contribution to the work of the Board will be limited for the present to consultation and purely advisory aid to the new Chairman.

As Chairman of the Editorial Board, Dr. Brumbaugh has ably continued the fine performance and tradition he had previously established for the magazine Industrial Quality Control. As its Founder and first Editor, he is terminating an outstanding period of service to the magazine and thus to the American Society.

The Officers and the Executive Committee express to Dr. Brumbaugh the sincere thanks and appreciation of the Society for his loyalty and constant self-sacrifice to the cause of a creditable Quality Control magazine. They are grateful for his consent to continue on the Editorial Board, and they wish him every success in his new work.

PROFESSOR WESCOTT NEW CHAIRMAN OF EDITORIAL BOARD

At its meeting on 27 April, the Executive Committee appointed Professor Mason E. Wescott of Northwestern University to succeed Dr. Brumbaugh on 1 July as Chairman of the Editorial Board. Professor Wescott has been a member of the Editorial Board and has been assisting Dr. Brumbaugh actively in the planning and arrangement of recent issues of Industrial Quality Control. The Executive Committee feels it is most fortunate in securing Professor Wescott's consent to accept the Chairmanship.

CONVENTION

As this issue of Industrial Quality Control goes to press, the First Annual Convention of the Society is about to convene in Chicago with widespread promises of success and great benefit to all who may find it possible to attend. The July issue of the magazine will record the degree to which these promises have been fulfilled.

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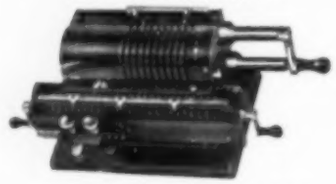

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AUDITING COMMITTEE APPOINTED

At its meeting on 26 April, the Executive Committee appointed the following members to serve on the Auditing Committee for 1946-47:

Chairman, H. L. Jones—Chicago
H. R. Bolton—Buffalo
G. R. Gause—At Large
P. A. Robert—Southern Tier
Joseph Sadowski—Syracuse

RECIPROCITY

At the Executive Committee meeting in New York on 27 April, it was brought out in discussion that a number of the Sections have adopted the practice of charging non-members for attendance at ordinary local Section meetings.

The Executive Committee had no comment on the principle involved in this practice, — in fact a majority of the Committee appeared ready to endorse it as a policy in those cases where the local Section favors it. Practically all of the members of the Executive Committee were obviously opposed in principle however, to the general application of this policy toward American Society members.

The Executive Committee recognized that an "At Large" American Society member who frequently attends the meetings of a particular Section, should pay for such meetings. Similarly an American Society member of a Section, who frequently attends the meetings of a Section not his own, should pay for those meetings.

With the above exceptions, it was the unanimous feeling of the Executive Committee that all Sections would be well-advised to work out arrangements under which American Society membership cards would admit their holders to all regular Section meetings.

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Step by step procedure for establishing quality control program that provides permanent record, and information regarding state of control at each machine.

USE OF INSTRUMENTS FOR CONTROLLING QUALITY, J. Manuele.
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Principles of quality control program based on inspection by method of variables, which requires that characteristic to be controlled be measured on continuous scale, so that closeness of conformity to specification, or amount of deviation of rejected parts from specification can be determined; sensitivity and accuracy of indicating gages required; gage department layout and facilities; gage use ,maintenance and current applications.

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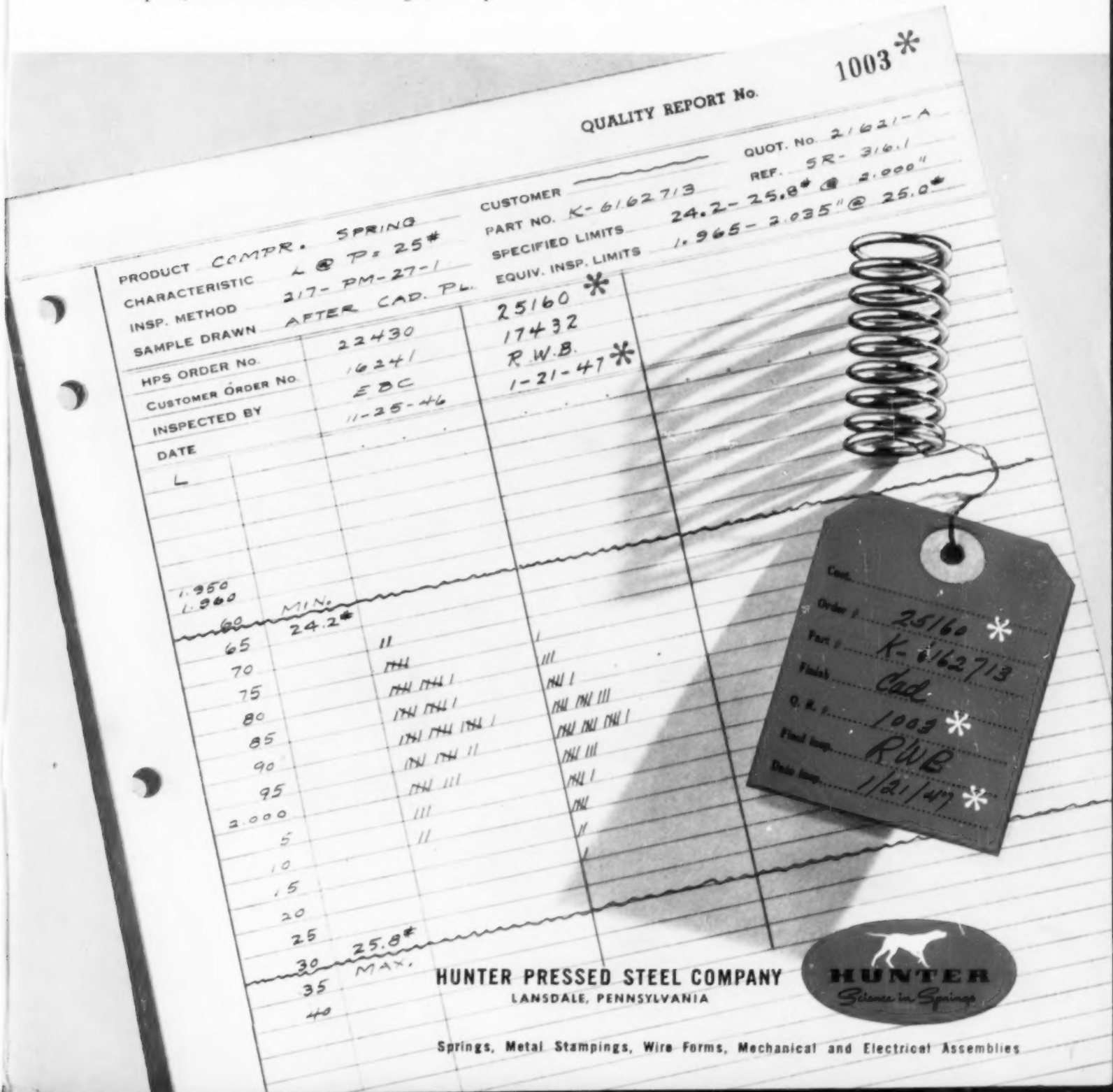
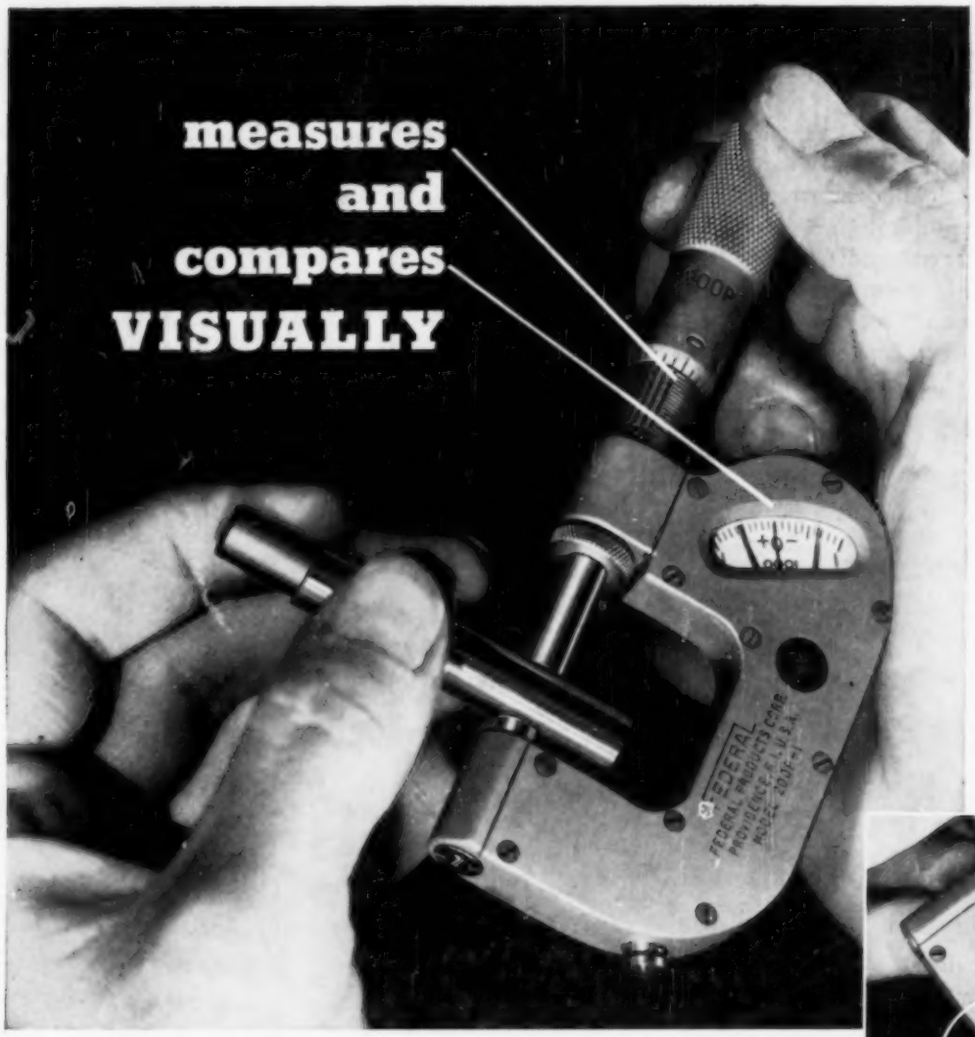
That day is here for Hunter customers.

Hunter now makes available to customers a report of the measured test loads for *every* lot of springs in the form of a frequency distribution. These Q.R.'s (Quality Reports) will be mailed to chief engineer, inspector or other person designated. The Q.R. of the sample drawn from *each* lot of *every* item will be sent as the lot clears Hunter's final inspection.

These reports enable one to compare quality lot-for-lot, consider tolerance revisions, reduce customers' sampling without sacrificing quality insurance . . . will lead eventually to a comparison of quality vendor-for-vendor.

Hunter believes it is the first in industry to make this valuable service available to all customers.



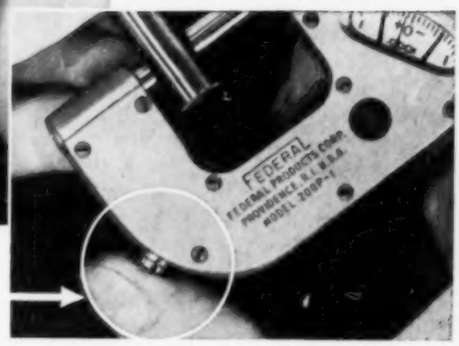


without errors of "feel"

With this Indicating Micrometer, you *see* rather than *feel for* the dimension. You know when you're right . . . In a top quality micrometer you have a Dial Indicator which *shows* the precise measurement in tenths (.0001"). This eliminates the human variations in setting the spindle at its required uniform pressure.

You get four additional positive advantages. First, by retracting the lower anvil with the push button, you have a snap gage to use on job lots. Second, the tolerance hands on the dial make it easier to determine the dimensions which are within tolerance. (This is a natural for Statistical Quality Control.) Third, you get Tungsten Carbide Anvils. Fourth, all except the spindle is finished in beautiful, rust-proof dull chrome.

The Federal Indicating Micrometer is a basic instrument you need today. We invite you to write for a descriptive folder.



Retracting this button enables you to use the Indicating Micrometer as a snap gage on job lots

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